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TABLE OF CONTENTS

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THE JAM ON INFRARED IMAGE MISSILES

Liang Baichuan

Translation of "Dui Hong Wai Cheng Xiang Zhi Dao Dao Dan De Gan Rao"; Shanghai Astronavigation, No.3, 1995, pp 49-52

ABSTRACT On a foundation of the study of principles and properties associated with infrared image guidance, stress is laid on the study of jamming mechanisms and techniques associated with infrared jamming bullets against infrared guidance missiles.

In conjunction with this, a discussion is carried out with regard to the selection of parameters associated with infrared jamming bullets.

KEY WORDS Infrared image guidance Infrared jamming bullet Center of mass tracking Interrelated tracking

1 SUMMARY

The development of infrared guidance heads has already had more than 30 years of history. Passive type infrared guidance heads possess the characteristics of high guidance precision, operating concealment, and not being easily subject to electromagnetic jamming. Equipment is simple. Manufacturing costs are comparatively low. Counter jamming capabilities of point source type infrared guidance heads are bad. They are easily subject to infrared jamming bullets and interference associated with infrared jammers. Third generation infrared guidance heads opt for the use of infrared image guidance technology. Not only are hit accuracies high. Moreover, counter

jamming capabilities are very strong. What is called infrared image guidance is nothing else than opting for the use of real time imagery devices, supplying two dimensional infrared imagery information. Use is made of modern imagery processing technology and mode differentiation technology. Automatic processing is

carried out with regard to target imagery.

2 OPERATIONAL PERFORMANCE OF INFRARED IMAGE GUIDANCE

2.1 Tracking Modes

Starting out from tracking information acquisition mechanisms, infrared image guidance tracking modes can be divided into two types.

a. Tracking Modes Based on Imagery Gray Levels and Their Distribution

Belonging to this type of tracking mode are contrast gradient tracking, interrelated tracking, moving target tracking, gray level histogram tracking, t statistics tracking, and so on. The modes described above only require taking imagery of gray levels and their distribution characteristics. Use is made of measurements of difference values associated with the gray levels of two frames of imagery (or their statistical values) in order to precisely determine the amount of movement of the target and to carry out tracking of the target. This type of tracking mode is capable of operating in situations with comparatively low gray level contrast. Due to the fact that algorithm sturctures are ones that take image elements as their foundation, therefore, tracking precisions are greater than one image element. Calculations associated with measurements of imagery gray level difference values are comparatively sensitive to noise. Therefore, error accumulations during the process of tracking are unavoidable.

b. Tracking Modes Based on Target Shape Characteristics

Examples would be edge tracking, regional balance method tracking, center of mass tracking, characteristic (symbol) matching tracking, and so on. This type of tracking mode requires extracting target shape characteristics. In conjunction with this, use is made of target shape characteritics in order to precisely determine the spacial positions of targets. As a result, there is also a need for a certain imagery gray level contrast. Due to the fact that calculations associated with shape characterisitics can be refined on the basis of image elements. Therefore, there is relatively high tracking accuracy.

Errors between frames will not produce accumulations. They possess comparatively strong inhibiting capabilites with regard

to noise.

In missile guidance systems, those, at the present time, for which option is made for use relatively often are two types of modes--interrelated tracking and center of mass tracking. For example, the U.S. White Sands target range tracking system, "Young Domestic Animal" missiles, "Tank Destroyer" missiles, and LANTIAN nacelle systems are mostly like this. As far as characteristic matching systems are concerned, due to the fact that they possess quite strong counter barrage jamming capabilities as well as comparatively high tracking precisions, at the present time, they are still in the laboratory research stage. However, this type of tracking mode is one type of mode having very good development prospects. /50

2.2 Tracking Wave Filtration

In the same way as other tracking systems, infrared image guidance missile tracking systems will produce situational noise because of sudden target maneuvers or other fortuitous maneuver jamming. Of course, measurment noise will also be introduced due to changes in measurement conditions. The noise described above will ultimately influence system tracking accuracies. In order to guarantee drops in tracking precisions not being caused under conditions associated with situational noise and measurement noise interfrerence, in tracking circuits, tracking wave filters are normally introduced. The models of tracking wave filters are α-■ wave filtration devices, α-■-■ wave filters, Karmann wave filters, as well as specialized filters. Tracking filtration devices are capable of guaranteeing continuous tracking of targets by tracking systems under short term jamming effects and maintaining tracking accuracies at sub image element level. Coordinating tracking filters and reliability estimates, it is possible to complete multiple types of intelligent tracking functions.

2.3 Tracking Predictions

At times, due to various causes--for example, being subject to barrage type jamming--measurement signals from targets may possibly be lost. At these times, tracking prediction devices in tracking systems will, on the basis of some frames of tracking status before loss of the target, extrapolate movement parameters associated with target measurement parameters after the loss. This is nothing else than what is called tracking prediction.

After jamming disappears, tracking devices turn predicted status into normal tracking status. Tracking predictions are divided into multiple kinds of forms, such as, nonlinear predictions and linear predictions, square predictions and mixed predictions, and so on. They are applied with a view to actual situations.

2.4 Target Identification

Target identification is used in the differentiation of targets and jamming materials as well as the differentiating of multiple targets. Target identification methods are comparatively numerous. There are such ones as movement track identification, spectral identification, brightness identification, image identification, and so on. Considered from the angle of imagery, primary use is made of image differentiation methods. They use statistical differentiation as a fouundation. There is no requirement with regard to the detailed structure of images. With regard to the identification of established targets, fixed templates are normally loaded before the fact. In the case of dual option (or N option) target differentiation, it is necessary to draw up decision criteria before hand. During imagery differentiation, one must first of all carry out the separation of target areas within imagery. After that, the image characteristics associated with independent target areas are extracted and divided up. Finally, on the basis of statistical classification rules, determinations are made of target types.

3 COUNTERMEASURE TECHNOLOGIES AGAINST INFRARED IMAGE GUIDANCE MISSILES

In infrared image tracking systems, the key technologies are tracking algorithms. At the present time, tracking algorithms are basically divided into two types--wave gate tracking algorithms and interrelated tracking algorithms. The former is capable of precisely determining that a certain part of a received scene is a target image. Moreover, tracking signals are produced in the differentiated target. As far as the latter is concerned, going through calculations, it is possible to obtain correlation functions between imagery produced by sensors and stored reference images. This is nothing else than the adjustment of tracking points on the basis of changes associated with locations where these two images match the best.

3.1 Center of Mass Tracking Modes

With regard to center of mass tracking modes, tracking points are primarily acquired by going through calculations of target centers of mass within wave gates. As a result, interference effects can primarily appear in the two areas below.

a. Jamming of Wave Gates

After the introduction of jamming, it makes tracking wave gates follow the movements of jamming objects. In conjunction with this, there is a constant expansion, moving away from targets, until, finally, there is an opening up to the entire field of view. This makes tracking systems carry out search again, implementing target acquisition. In this type of situation, jamming is successful.

b. Destruction of Tracking Precision

This is primarily destruction of center of mass calculations. In the cases of many tracking systems, they all have this index of tracking precision. If tracking systems cannot reach this index requirement, they are then considered to have failed to track. Jamming is successful. After the introduction of jamming objects, targets within wave gates and jamming objects will have center of mass calculations carried out on them together, thus making centers of mass deviate off original tracking points. In terminal guidance phase, the distances of deviation exceed permissible tracking distances, at which time, it is then considered that the jamming is successful.

What should be pointed out is that, at the present time, the majority of tracking systems associated with center of mass tracking modes all possess differentiation functions. In situations where targets and jamming objects are separated, systems will cover wave gates and eliminate jamming objects. Therefore, speaking in terms of center of mass tracking modes, it does not matter in which area the jamming effects are displayed. If targets and jamming objects are separated from each other, jamming is then not able to be successful. It is only under conditions associated with a fusion of them that it is then possible to make jamming successful. This then requires that the firing direction of jamming bullets, the relative speeds of jamming bullets with respect to targets, as well as the effective areas of jamming bullets be mutually coordinated.

/51

3.2 Interrelated Tracking Modes

The two important indices associated with interrelated tracking modes are matching position errors and matching probabilities. Due to the fact that the instants associated with the gathering of these two frames of imagery are different, there is, in addition, the existence of noise. Between them, there will definitely be differences. If one has the existence of jamming objects, the differences between them will be even greater. As a result, the actual matching points after going through correlation operations and the correct matching points will give rise to deviations between them. This is nothing else than matching position error. Due to the existence of random noise, precise determinations of extreme value point locations will be associated with a certain probability. Matching precision refers to the possible range associated with correlation value extremes--using a certain probability (matching probability)-- occuring in the vicinity of accurate matching spots. Corresponding matching probabilities are then defined as probabilities associated with correlation value extremes appearing within fixed accuracy ranges. Therefore, with regard to interrelated modes, the jamming effects of jamming bullets must be evaluated in terms of the influences of jamming bullets on matching positions, matching accuracies, and matching probabilities.

3.3 Jamming Methods Associated with Infrared Image Guidance Systems

Infrared image guidance systems are mostly passive systems. They detect targets using differences between radiation from targets themselves and the background. In conjunction with this, targets are tracked. As a result, infrared jamming methods can be divided into two types--active jamming and passive jamming.

a. Examples of active jamming are such things as infrared jamming bullets, infrared jammers, and so on.

b. Examples of passive jamming are such things as infrared camoflage, infrared stealth, and so on.

Here, we are primarily discussing active jamming. Typical infrared point source jamming bullets and infrared jammers have no way to counter infrared image tracking systems. Because infrared image missiles carry out imaging against targets and backgrounds, they opt for the use of such technologies as image processing, mode identification, modernized control, and so on. Moreover, it is also necessary to carry out processing with regard to such information as target areas, movement parameters, as well as shapes, and so on. As a result, target information

acquired will be much greater than infrared missiles opting for the use of modulation disk methods. Thus, the difficulties associated with jamming infrared image missiles are also then comparatively much greater.

3.4 Discussion With Regard to Jamming Bullet Parameters

3.4.1 Center of Mass Tracking Mode

With regard to center of mass tracking modes, the size of tracking wave gates is autoadapted and adjusted on the basis of target position and the dimensions of target imagery used. Speaking in terms of systems that do not have identification capabilities, wave gates are autoadapted and adjusted on the basis of the combined locations and dimensions of targets and jamming objects. Tracking points are precisely determined on the basis of the combined center of mass of composite imagery associated with both target images and jamming objects. Following along with constant increases in the distances between jamming objects and targets, wave gate dimensions are also constantly enlarged, until they are finally expanded to the entire field of view. Speaking in terms of systems that possess differentiation capabilities, when jamming objects and targets are separate, systems are capable of distinguishing targets and jamming objects. Moreover, new wave gates are set up on the basis of target positions and dimensions. At this time, jamming will not play a role. Due to the fact that image differentiation capabilities against targets, which are associated with infrared imagery systems, are limited, imagery, after targets and jamming objects somewhat overlap and guidance systems will then take jamming objects and targets and fuse them together, acts as the object of tracking. At this time, wave gates will gradually expand. In this way, jamming objects then begin to play a destructive role with regard to guidance system guidance precisions. Requirements associated with jamming bullets are as follows.

a. Jamming bullets should possess large areas in order to facilitate being able to fuse with targets, and, in conjunction with that, sustain it for a certain period of time.

b. Relative speeds of movement between jamming bullets and targets should not be too great in order to guarantee comparatively long periods of fusion.

c. Requirements with regard to jamming bullet gray levels are not high. It is only necessary to slightly exceed target gray level values, and that is all.

d. Jamming bullet combustion times should be on the order of a few seconds in order to guarantee having a certain period of fusion.

3.4.2 Interrelated Tracking Mode

With regard to interrelated tracking modes, they do not set

wave gates. Simply in order to reduce amounts of calculations--within the whole field of view--a correlation area of a certain size is selected in order to carry out calculations. If there begin to be targets and jamming objects existing at the same time within correlation areas, no matter whether targets and jamming objects are fused or not, it is not at all possible to eliminate jamming objects and only carry out calculations with regard to targets. It is generally believed that interrelated tracking modes do not have differentiation problems. Due to the fact that interrelated tracking methods adjust tracking points on the basis of the differences between real time images and reference images, we always hope that tracking points are as close as possible to jamming objects and far away from targets. Therefore, requirements with regard to jamming bullets are as follows.

a. The larger the area of jamming objects is, the better--values when areas increase so that jamming effects grow to be indistinct. /52

b. The larger jamming bullet gray levels are, the better. It is possible to adopt jamming bullet gray levels that are 3-5 times target gray levels.

c. The larger relative movement speeds of jamming bullets and targets are, the better jamming results are.

d. Jamming bullet combustion times must be long in order to make the accumulation of errors given rise to by jamming against missile tracking adequately large.

4 CONCLUSIONS

Jamming interrelated tracking modes will be somewhat easier than jamming center of mass tracking modes. The reason is that interrelated tracking modes have no way to eliminate accumulated errors. After effective jamming has once been created, tracking points deviate from target areas. It is then possible to believe that the jamming is successful. However, center of mass tracking modes, by contrast, are not this simple. They require effective jamming sustained until missile terminal guidance phase and even up to unguided phases. Therefore, as far as center of mass tracking modes are concerned, requirements with regard to jamming bullets are even more stringent. Implementing jamming is also comparatively difficult.

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PREVIEW OF NEXT ISSUE'S CONTENTS

--Analytic Research on Interference Associated with Space Release of Final Stage Remaining Rocket Propellant in Low Gravity States

--Fuzzy Neural Networks Based on BP Algorithms

--Influences on Combustion Speed of Remaining Amounts of Styrene in High Burn Speed Propellants

--Satellite Borne Microwave Radiometer System Calibration Techniques

--Analytic Study of Signal Acceleration Systems During Rendezvous

of Missiles and Targets
--Releasable Electronic Warfare
--Study of High Power Operating Characteristics of Nickel-Cadmium Batteries

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COUNTERMEASURES ASSOCIATED WITH THE JOINT TACTICAL INFORMATION DISTRIBUTION SYSTEM

Xu Canxun

Translation of "Lian He Zhan Shu Xin Xi Fen Fa Xi Tong De Dui Kang"; Electronic Countermeasures, No.2, 1995, pp 1-7

[ABSTRACT] Guided by the best interference theory in communications jamming, this article goes through a comprehensive analysis of JTIDS characteristics. It adopts strategies which avoid the stengths and attack the weaknesses, putting forward multiple frequency channel wide band interrelated jamming systems. Operating modes associated with saw tooth waves and dummy code group composite modulation as well as methods using ground or airborne directional jamming are capable of effectively carrying out jamming with respect to JTIDS. Moreover, in situations where jamming powers do not increase, it is possible to implement effective jamming against multiple JTIDS nets associated with the same area simultaneously.

[KEY WORDS] Communications jamming Joint Tactical Information Distribution System Electronic jamming technology

As far as Joint Tactical Information Distribution Systems are conerned, they are simply called JTIDS and are integrated U.S. communications, guidance, and recognition systems developed in a unified way by the U.S. Navy, Army, and Air Force in order to adapt to joint triservice combat. They are capable of rapidly collecting various types of intelligence information coming from the battlefield, commanding coordinated triservice combat in real time so as to fully bring to bear the intergrated combat efficiencies associated with units. This article attempts to study the use of electronic warfare to carry out effective jamming against JTIDS.

I. CHARACTERISTICS OF JTIDS PERFORMANCE

As far as JTIDS, which was developed in a unified way by the three U.S. military services, is concerned, the characteristics are that, within nets, there are many users. Capacities are high. Between the various users, it is possible to communicate at will, carrying out data and voice transmissions. Moreover, effective ranges are long. In conjunction with this, consideration is given to the fact that operations are carried out in electronic warfare environments. Option is made for the use of multiple types of signal carrier security measures, such as, skip frequency, direct expansion, as well as time skip, and so on. Multiple types of error correction measures as well information securing are also carried out on data. Comparing it to communications systems in the past, the performance is a leap in quality. It is basically capable of satisfying three service joint operational requirements. Moreover, JTIDS is also in the midst of further improvements. However, by the author's analysis, it is precisely because of the characteristics that it satisfies three service joint operational requirements, possesses multiple users, has large capacities, and the various users are capable of communicating at will, that improvements in its counter jamming capabilities are limited. Because of the characteristics described above, JTIDS opts for the use of time division multiple address operating methods. Each time slot is held by a certain user. To send one line of information, the time is 7.8 milliseconds long. In order to guarantee that the various users will all be able to make reception within this time slot, it is necessary, after the transmission of information, to set up a protective section. The length of time is 2 milliseconds. However, giving consideration to skip times, by contrast, the length of time associated with information segments is only 3.4 milliseconds. Due to the fact that reception ranges of various users are different, it is necessary to place a synchronicity section in the header of information segments in order to make the various receiving users carry out precise information synchronicity with regard to signals. In this way, the data segments associated with actually transmiting information only send 109 bytes within 2.8 milliseconds. When error corrected encryption is carried out with regard to information, then, only 49 bytes are transmited. Taking off 4 heading bytes, only 45 bytes are sent. Each byte is 5 bits of information. By contrast, each time slot sends 225 bits of information, that is, information capacity is 28.8kbps, in order to adequately send the information associated with the various users within nets. Within operating frequency bands (width 153 MHz), comprehensive consideration is given to frequency skip and direct expansion methods. Adopting direct expansion, frequency width is 3.5 MHz. Opting for the use of MSK modulation, it causes basic code width to be capable of reaching 0.2

microseconds. Within bytes associated with widths of 6.4 microseconds, it is only possible to select for use 32 digit dummy code sequences. In order to send 5 bit information, N=32/5=6.4. Moreover, it causes direct expansion gains to be limited to around 8dB. Direct expansion signal width is 3.5 MHz.

It is only possible to make freqency channel intervals be 3 MHz. Then, in the entire operating frequency band, it is only possible to set up 51 individual frequency points to carry out freqency skips, limiting skip frequency gains to only reaching 17dB. With regard to the consideration of time skips, there are random changes within approximately 0-2.4 milliseconds--equivalent to time skip gains being (2.4+3.4/3.4=1.7(2dB). Then, the overall frequency expansion gain associated with JTIDS is approximately 27dB. Comparing to VHF (30-88MHz) skip frequency stations, frequency channel intervals are 25kHz. There are 2320 individual frequency points all together. Frequency skip gain is 34dB. JTIDS expansion frequency gains are low. However, on the other hand, due to each byte being 26 microseconds long, as far as each byte skipping a frequency channel is concerned, the skip frequency speed is very high. It is 38461.5 skips/second. Moreover, actual skip frequency signal sustainment periods are only 6.4 microseconds. However, VHF skip frequency station frequency skip speed is under 500 skips/second. Having analyzed the JTIDS counter jamming performance and characteristics described above--that is, the advantages and weak points--doing research from the angle of electronic jamming, one should then avoid the strengths and attack the shortcomings, correctly selecting optimum jamming systems for JTIDS. This article selects for use active, multiple frequency channel, wide band, interrelated obstructive types of jamming systems, but does not choose to utilize such jamming systems as traditional, passive, aimed type, tracking type, or transmission type ones, etc. As far as this kind of blocking type jamming system is concerned, it is particularly suited to jamming JTIDS communications systems associated with frequency expansion gains that are comparatively low. In conjunction with this, due to the fact that JTIDS network users are numerous and mobility is great, its users generally need to utilize omnidirectional antennas in order to guarantee their being able to communicate with users above and below, to the left and right, and forward and behind them. However, in the area of jamming, by contrast, it is possible to opt for the use of directional jamming antennas in order to aim at areas of enemy activity to carry out effective directional jamming. Antenna gains associated with making use of directional antennas are high. They are capable of making comparatively small jammer powers achieve effective jamming. Another characteristic of this kind of blocking type jamming is that--in situations where there are no increases in jamming power--it is possible, at the same time, to carry out effect jamming against multiple JTIDS nets in the same area. /2

II. JAMMING AGAINST JTIDS

U.S. military circles assert that, as far as the 20 year long history of the development of JTIDS is concerned, the cost in resources has been huge, and performance leads the world. Going through research and analysis, the author believes that JTIDS can be jammed. Moreover, he believes that, making use of current technology, it is possible to implement effective jamming againsts JTIDS. Tactically, it is also feasible.

(I) Jamming Systems

JTIDS uses jumps at 38461.5 per second to carry out rapid frequency skips. As a result, it is very difficult to carry out tracking type jamming against it. We know that 6.4 microseconds is equivalent to the propogating of electromagnetic waves approximately 2 kilometers. Even if the intercept, processing, and guidance times associated with jammers are very fast--as far as the sums of reception and jamming ranges (Rr + RJ) are concerned, however--if they exceed signal ranges (Rs) by 2 kilometers, so that Rr + RJ - Rs > 2km, then, when jamming arrives at communications reception terminals, communications signals associated with this skip frequency period will have already completed reception, and there will be no way to implement effective jamming. By the same reasoning, it is also difficult to implement transmission type jamming against it.

The author believes that the only effective jamming method for coping with very fast frequency skips is multiple frequency channel blocking type jamming [2]. That is, the implementation of jamming against the skip frequency channels at the same time. Due to the fact that the operating frequency bands that JTIDS is capable of making use of are limited--a total width of 153 MHz--there are only 51 frequency skip frequency points. Moreover, we know that, when JTIDS data opts for the use of error correction encoding, it is still possible to maintain normal communications even losing 50% of the information. As a result, it is necessary to jam over half (that is, 26) skip frequency points, and it is possible to achieve effective jamming. For instance, it is possible to block jam the 1122-1200 MHz frequency band (78 MHz wide, that is, 26 frequency channels)--which is to implement jamming against the 26 frequency points at the same time. Then, the jamming power multiplier value Kji (equivalent to the number of jamming frequency points) is 14dB. /3

JTIDS adopts direct sequence frequency expansion processing with regard to each byte. Due to the fact that the number of code keys is large (>1038), sequence periods are long (>1023), and levels of signal carrier security are high, it is very difficult to go through real time intercept to carry out decryption, grasp the direct expansion sequence pattern, and carry out jamming aimed at wave forms. By the same reasoning, there is a need to opt for the use of blocking type jamming [3]. Going through analytic comparisions, option should be made for the use of the same signal carrier frequencies, the same dummy code speeds, and, in conjunction with that, option should be made for dummy code modulation with the largest or comparatively large mutual correlation values associated with interrelated block type jamming, with jamming frequency widths of approximately 3 MHz. The jamming results are optimal. When reception of a certain frequency channel is jammed, at communication reception terminals, the jamming power associated with this frequency channel needs to be higher than signal power by $(\sqrt{N} = \sqrt{6.4})$

fold, that is, Kj2 is approximately 4dB. Effective jamming can be achieved.

As far as JTIDS is concerned, each time slot makes use of time skip measures. The time skip range is 0-2.4 millisecond random changes. Although the actual information transmission is only 3.4 milliseconds, in order, however, for the various terminal sets within networks to all be able to be effectively jammed--(due to the fact that the distances of various receiving terminal sets and transmiting terminal sets are not the same, the time periods associated with the reception of signals are, then, not the same and the distances associated with jammers and various receiving terminal sets are different)--in order to make various receiving terminal devices and transmiting terminal devices all show the appearance of jamming within signal reception time periods--going through analytical calculations--during jamming processes, it is necessary to transmit uninterrupted jamming continuously.

With regard to the analysis above, the author puts forward the optimal jamming system against JTIDS as being multiple frequency channel wide band interrelated jamming systems. That is, during periods of jamming, blocking type jamming is implemented against it. Multiple frequency channel jamming is transmited continuously at the same time. Each frequency channel makes use of dummy code modulated interrelated jamming.

This type of multiple frequency channel wide band interrelated jamming belongs to the catagory of blocking type jamming. Moreover, we know that JTIDS is capable of operating single nets within the same area and is also able to operate multiple nets. At a maximum, it is capable of operating 15-20 nets at the same time. The outstanding advantage associated with this type of jamming system is that, due to the fact that it is capable of sending out jamming of 26 frequency channels at the

same time, as a result, in situations where jamming powers do not increase, it is capable of carrying out effective jamming against all JTIDS nets associated with the same area. In actuality, when the number of JTIDS nets operating at the same time in the same area is increased, transmission powers required in order to achieve effective jamming can, on the contrary, be reduced. Because of the fact that, even if this type of meaningful jamming does not exist, when JTIDS nets in the same area increase to 20 or more, due to mutual influences between nets, the various nets are already made to experience comparatively great jamming.

This type of jamming system is not only capable of effectively jamming JTIDS communications. It is, at the same time, also able to successfully jam JTIDS navigational positioning and identification friend or foe functions.

Moreover, in order to realize the jamming systems described above, the author puts forward mode electric circuits associated with combinations of saw tooth wave super wide band frequency modulation and dummy code wide band modulation the use of which should be opted for. From theoretical analysis and practical application, the author arrives at the fact that, during saw tooth wave super wide band frequency modulation, the jamming powers associated with frequency components fo ± nF of various frequencies within frequency modulation frequency bands are:

$$Pn = \frac{1}{4}\frac{F}{\Delta fj}\{[C(\frac{\Delta fj + nf}{\sqrt{\Delta fj \cdot F}}) + C(\frac{\Delta fj - nf}{\sqrt{\Delta fj \cdot F}})]^2 + [S(\frac{\Delta fj + nf}{\sqrt{\Delta fj \cdot F}}) + S(\frac{\Delta fj - nf}{\sqrt{\Delta fj \cdot F}})]^2\}P_0$$

In this, F is saw tooth wave frequencies and is also frequency intervals associated with various components.

2■fj is saw tooth wave overall frequency modulation frequency deviation.

Po is overall jamming output power.

$C(\frac{\Delta fj \pm nf}{\sqrt{\Delta fj \cdot F}})$, $S(\frac{\Delta fj \pm nf}{\sqrt{\Delta fj \cdot F}})$ are Fresnel integrals, that is,

$$C(X)=\int_0^x \cos\frac{\pi}{2}t^2\cdot dt,\quad S(X)=\int_0^x \sin\frac{\pi}{2}t^2\cdot dt.$$

fo is central jamming frequency.

When super wide band frequency modulation 2■fj>>F, (modulation frequency index ■fj/F>>1), the formulae described above can then be simplified as: /4

$$P_n \approx \frac{F}{2\Delta fj}\cdot P_0$$

That is to say that, within frequency modulation frequency bands, the jamming powers associated with various frequency components are basically the same. Moreover, uniform, comb shaped jamming frequency spectra are presented, as is shown in Fig.1(a). Due to the fact that, within jamming frequency bands, there are m = 2■jf/F frequency components, the jamming powers associated with various frequency components are then equal to 1/mth the overall jamming output power.

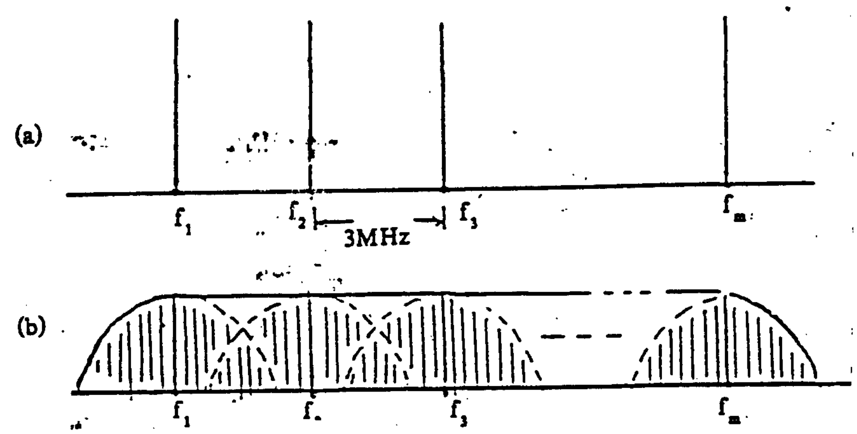

图 1 多频道宽带相关干扰

Fig.1 Multiple Frequency Channel Wide Band Interrelated Jamming

After going through saw tooth wave super wide band frequency modulation, various frequency components are continuous waves. As far as making use of undamped waves to jam direct expansion signals is concerned, it is also possible to obtain comparatively good jamming results. However, from optimum jamming theory, one obtains the fact that the absolute optimum jamming should lie in frequency ranges and signals that are the same. Use should be made of wide band jamming of direct expansion signals. The reason is that this type of regular continuous wave is capable of being eliminated by the use of many such measures as jamming offset methods, autoadaptive electric circuits, and so on. Further research and analysis by the author arrived at the fact that, at the same time as carrying out saw tooth wave super wide band modulation on carrier waves, implementing dummy code wide band modulation on carrier waves is equivalent to carrying out dummy wide band modulation simultaneously on each of the frequency components and causing each component to be turned by continuous waves into signal related wide band jamming, as shown in Fig.1(b). Detailed theoretical analysis can be derived omiting [4][5]. As far as saw tooth wave frequencies are concerned, 3 MHz is selected for use. Saw tooth wave overall frequency modulation frequency deviation is 78 MHz in order to obtain continuous wave signals of equal strength associated with 26 frequency channels for which 3 MHz was the frequency channel interval. With regard to dummy codes, option is made for the use of 0.2 μs code elements and signal related dummy random sequences. After going through modulation of carrier waves at the same time as saw tooth waves, 26 undamped signals were all taken and turned into 26 wide band jammings associated with frequency widths which were, respectively, 3.5 MHz. The jamming wave forms and frequency spectra were of the same type as signals. As a consequence, it is possible to achieve good jamming results. Moreover, this circuitry possesses superiorities. The jamming produced presents comb shaped jamming of equal power in frequency domains (multiple frequency channel jamming). The strengths of the various jamming components are the same. Frequency intervals and signal frequency intervals match up. They are similarly 3 MHz. On the edges of frequency bands, jamming energies drop off steeply and do not influence other frequency band signals. In time domains, jamming presents undamped envelopes. It is possible to make full use of power amplifier power capacities, outputing full power from beginning to end. Circuitry is simple. Adjustment is convenient. However, as far as other circuitry is concerned, if super wide band noise is amplified, although it is possible to realize in frequency domains a uniformity of frequency spectra, in time domains, however, amplitude changes are very large. For example, with respect to one kilowatt power amplification, when peak value

output is one kilowatt, in reality, the average output power can be only 100 watts. Also, for example, as far as noise or dummy code super wide band modulation or phase modulation are concerned, jamming after modulation is then continuous in time domains. However, in frequency domains, (sinc)2 state power spectra are presented. The various jamming component powers are not uniform [6].

2. Jamming Methods /5

JTIDS is primarily used in air force operations, assisting in sea and land combat. It currently uses U.S. E-3A aerial early warning and command aircraft, commanding and guiding various tactical aircraft, for example. When the enemy are in an offensive posture, early warning aircraft will, for instance, patrol airspace 350 kilometers from the forward edge, constantly recieving information sent from various reconnaissance aircraft and attack aircraft, as well as continuously acquiring target information from radars on early warning aircraft. On the foundation of real time information processing, timely strategies are worked out, commanding and guiding various combat aircraft to implenment attacks on various types of targets. We can opt for the use of ground jamming methods, emplacing mobile ground jamming stations at important friendly cities and bases or on the forward edge. For example, it is possible to emplace jamming stations in friendly areas 50 kilometers from the forward edge, as shown in Fig.2. In accordance with basic jamming methods, the overall jamming transmission powers needed for jamming stations to achieve effective jamming are as shown in Fig.3.

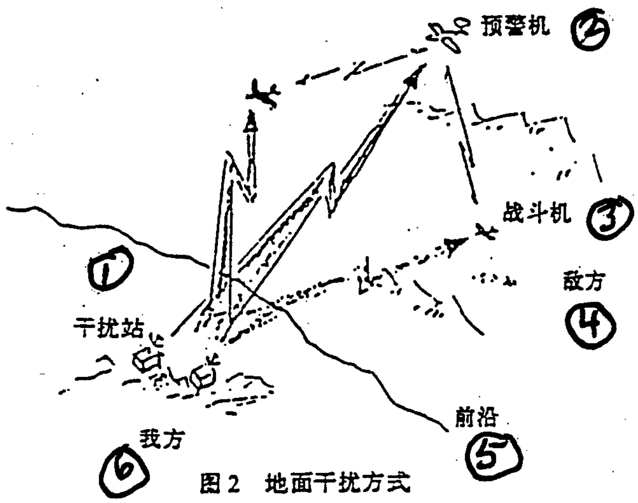

图 2 地面干扰方式

Fig.2 Ground Jamming Methods (1) Jamming Station (2) Early Warning Aircraft (3) Fighter (4) Enemy Area (5) Forward Edge (6) Friendly Area

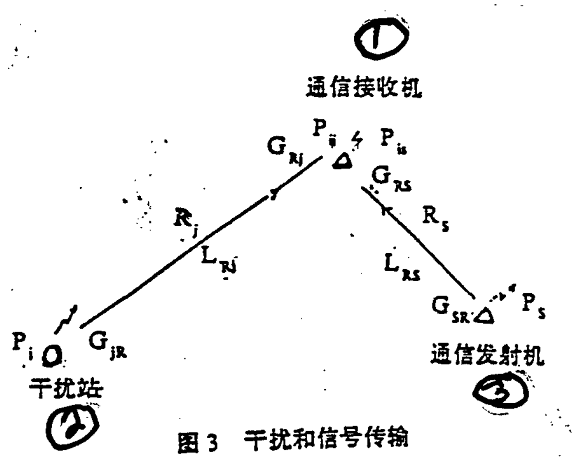

图 3 干扰和信号传输

Fig.3 Jamming and Signal Transmission (1) Communications Receiver (2) Jamming Station (3) Communications Transmiter

$$P_j = K_j \cdot P_s \frac{G_{SR} \cdot G_{RS}}{G_{JR} \cdot G_{RJ}} \cdot \frac{L_{RJ}}{L_{RS}}$$

In this, Kj is the power ratio of jamming and signal (Pij/Pis) to achieve effective jamming and which must be recieved by reception terminals. From the analysis above, it can be known that, when jamming is transmited continuously and Kj = Kj1 + Kj2 = 14+4 = 14dB, information destruction can reach above 50%. There is no way for normal reception.

Ps is communications sending power. The power of transmiters currently installed on fighter aircraft is 200 watts (23dB). Early warning aircraft transmiter power is 1000 W (30dB).

GSR is the sending antenna gain associated with communications transmission antennas in the direction of receivers.

GRS and GRJ are, respectively, reception antenna gains associated with communications reception antennas in the directions of communications senders and jammers.

Due to flight maneuvers required by fighters and early warning aircraft, the antennas are omindirectional aerials. GRS, GSR, and GRJ are all set as 2dB.

GJR is the gain associated with jamming transmission antennas in the direction of receivers.

In ground jamming stations, it is possible to opt for the use of high gain directional jamming antennas--for example, reflection plane antennas or array antennas. Among these, reflection plane antennas are capable of opting for the use of cut parabolic surface antennas. As far as each antenna gain GB is concerned, when it reaches 17dB(50), the horizontal surface main lobe width ■B is approximately 60°. The vertical plane main lobe width ■8 is approximately 6°.

Due to the fact that GB = 2x104 /■B ■ ■B,
■B ■B = 2x104 / GB = 2x104 / 50 = 400 /6
Then, jamming stations are 350+50km = 400km from early warning aircraft. In a horizontal plane, it is possible to cover approximately 400km. Jamming is capable of completely covering early warning aircraft activity ranges. In a vertical plane, it is possible to cover approximately 40000m. Jamming is capable of

completely covering early warning aircraft flight altitude ranges.

LRj and LRS are, respectively, jamming and signal electromagnetic wave transmission losses. In this case, signal and jamming are air to air or ground to air transmissions. They are free space transmissions. The transmission losses and the distances squared form direct proportions. Then, LRj / LRS = RJ2 / RS2 . Rj and Rs are, respectively, jamming range and signal range.

When jamming the information received by early warning aircraft, that is, when jamming the information which various tactical aircraft send to early warning aircraft, early warning aircraft are communication receiving terminals.

Let RJ = RAB = 400km and RS = RBD = 140km

RJ / RS = 2.8 and LRJ / LRS = 9dB

Pj = Kj + Ps + GSR + GRS - GJR - GRJ + (LRj - LRS) = 18 + 23 + 2 + 2 - 17 - 2 + 9 = 35dB(3000W)

Then, option is made for the use of 3000W jamming radiated powers. It is possible to effectively jam various tactical aircraft when they are more than 140km away from early warning aircraft, giving early warning aircraft information, as shown in Fig.4. In this, the shaded areas are effective jamming zones. In the Fig., A is the jamming station. G is the early warning aircraft.

When jamming early warning aircraft sending information to various fighters, the various fighter aircraft are communications reception terminals.

Let a certain fighter be the point E in Fig.4, that is, Rj = RAE = 200km. RS = REB = 200km.

Rj / RS = 1, LRJ / LRS = 0dB

Pj = 18 + 30 + 2 + 2 - 17 - 2 + 0 = 33dB(2000W)

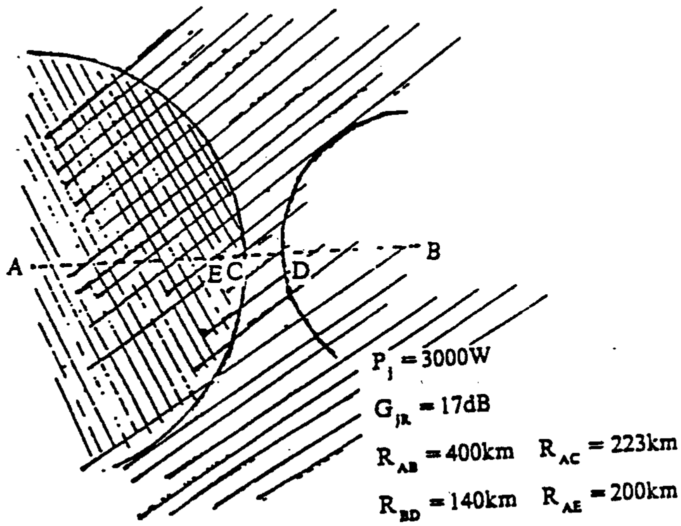

图4 对JTIDS有效干扰范围

Fig.4 Effective Jamming Ranges Against JTIDS

From further calculations, it is known that, when various tactical aircraft are in the shaded zones of Fig.4 and option is made for the use of 3000W jamming transmission powers, it is possible to effectively jam the information given by early warning aircraft to tactical aircraft. /7

From Fig.4, it can be seen that, opting for the use of 3000W jamming transmission powers, it is possible to effectively jam the majority of fighters sending information to early warning aircraft and, at the same time, effectively jam the information given by early warning aircraft to fighters approaching friendly areas. Moreover, going through calculations, it is possible, at the same time, to effectively jam information sent between various fighters close to our forward edge. Thus, it is possible to effectively jam this JTIDS network.

We are capable of opting for the use of one jamming station. However, it is more appropriate to opt for the use of two or multiple jamming stations. The reliability is high. Moreover, the transmission power of each jamming station can be correspondingly reduced. For example, opting for the use of three jamming stations, each station is then only required to transmit 1000 watts of jamming power. When multiple jamming stations depart from appropriate range dispositions, simultanously transmit jamming, and jamming frequency bands associated with transmissions during any time period are the same, the enemy has no way of respectively doing direction finding and positioning against them. It is possible to avoid antiradiation missile tracking and attacks. Besides this, it is also possible to make the enemy autoadapt zero adjustment communications antennas to lose their effectiveness.

When, at important points on the battlefield, in key directions, and at key moments, our side is capable of

concentrating forces to form a fist and acquire a certain air supremacy, we are also able to opt for the use of aerial jamming methods. As far as implementing aerial jamming methods is concerned, the range of jamming roles is even larger. It is possible to effectively jam JTIDS air to air communications, air to ground communications, and it is also possible to effectively jam the ground to ground communications and sea land communications, etc., in order to comprehensively jam various types of communications methods associated with JTIDS. Moreover, airborne jamming possesses the characteristics of flexible maneuver combat. By the same reasoning, it is appropriate to opt for the use of two or multiple jamming aircraft to transmit jamming at the same time. When JTIDS only uses ground communications, due to the fact that ground wave propogation losses and the fourth root of distances form direct proportions, it is appropirate to opt for the use of aerial jamming methods. It is also appropriate to opt for the use of ground distribution type jamming, air dropped on the ground in the vicinity of command centers in order to jam their reception of information sent from various other terminals.

From the above, it is possible to know that JTIDS can be jammed. In war time, at important points on the battlefield and key moments in time, the carrying out of effective jamming of the enemy JTIDS is capable of destroying the normal operations of tactical C3I systems and very, very greatly reducing the overall combat capabilities of enemy forces.

We believe that where there is a spear there is a shield. Where there is a shield, there is a spear. Electronic countermeasures are developing in the midst of ceaseless struggle. We must discover the enemy's weak points in a timely manner, making use of our advantages in order to constantly achieve victory in electronic warfare.

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[1] The translator refers to the author as Xu Canxun. A more careful inspection reveals that this author's name is actually Xu Muxun.

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GROUND RECONNAISSANCE SYSTEMS TO COPE WITH AERIAL EARLY WARNING AIRCRAFT AND JAMMING PLATFORMS

Tao Benren

Translation of "Dui Fu Kong Zhong Yu Jing Ji He Gan Rao Zai Ji De Di Mian Zhen Cha Xi Tong"; Astronavigation and Electronic Countermeasures, No.2, 1995, pp 40-44

ABSTRACT This article describes in a general way aerial early warning aircraft and electronic warfare aircraft, analyzing the various types of signal characteristics they are capable of intercepting and providing for ground reconnaissance systems. In conjunction with this--on this foundation--it puts forward basic concepts associated with reconnaissance aerial early warning aircraft and jamming platforms. It discusses the basic designs associated with this type of ground reconnaissance system as well as such questions as how to provide effective ground support for ground to air or air to air antiradiation missile attacks on aerial early warning aircraft or electronic warfare aircraft.

KEY WORDS Early warning aircraft Electronic warfare Jammer Aircraft Reconnaissance Surveillance radar Air to air missile

1 GENERAL SURVEY OF AERIAL EARLY WARNING AND ELECTRONIC WARFARE AIRCRAFT

An analysis of recent instances of world wars clearly shows that, once there is the appearance of military clashes, aerial early warning aircraft and electronic warfare aircraft will necessarily pose a severe threat to national defense. As a result, the use of what types of means should be adopted in order to cope with these two types of aerial threats is an important problem which urgently awaits solution at the present time. In order to find a type of measure which is realizable in practical terms and workable, there is a need to first of all understand and analyze the basic status of these two types of threats and

their key characteristics.

1.1 Aerial Early Warning Aircraft

Platforms associated with early warning aircraft can be specialized large model aircraft and helicpoters. They can also be balloons hanging at high altitudes. They are organically combined with long range surveillance radars and other sensors--completing such tasks as early warning, control, as well as communications, and so on. Early warning aircraft are normally positioned 150km away from the forward edge of the combat area. They fly in circles at altitudes around 9km off the ground. Early warning aircraft are comprehensive systems composed of multiple sensors. The sensors carried are primarily airborne early warning surveillance radars and identification friend or foe devices. Some are also fitted with photoelectric sensors, and so on. The main function associated with early warning aircraft is combat command. Therefore, they must have communications systems in order to carry out communications between airborne aircraft as well as from air to ground.

Early warning aircraft at the present time still do not have very effective self-defense capabilities. They mainly depend on operating far from the combat zone and using combat aircraft formations to provide protection. There are certain early warning aircraft which are already equiped with both foil strip dispensers associated with missile warning functions and alarms using infrared to realize protection against infrared guided missiles. In conjunction with this, they launch tracer rounds in order to protect themselves. Ideal systems are capable of carrying various types of jammers used for self-defense. From this, it can be seen that, on early warning aircraft, such things as active radiation surveillance radars, identification friend or foe (IFF), guidance systems, as well as communications systems, and so on, then supply for us advantageous conditions for reconnoitering early warning aircraft.

Guidance system powers are very small. They are only a few watts to a few tens of watts. Therefore, they are not too easy to intercept. Identification friend or foe frequencies are around 1GHz. Peak value powers are also not large. Generally, query devices are 1kW-1.5kW. Response devices are around 500W. As far as communications systems are concerned, E-2C and E-3A, for example, are already equiped with Joint Tactical Information Distribution Systems (JTIDS). The operating frequency is 960-1215Mhz. Option is made for the use of random code expansion frequency and skip frequency systems. The communications range can reach 500-900km. It is possible to see that their radiated

powers are very strong. The most key ones are airborne surveillance radars: Their radiated powers are even stronger. All are on the order of MW. Airborne radars include three types--early warning radars, battlefield surveillance radars, and maritime search radars. Their tactical and technical properties also vary with differing missions. Surveillance radars have already gone through four generations of improvements one after the other. What is installed currently is an improved AN/APS-139 model of the third generation AN/APS-138 surveillance radar which was delivered in 1987. It is estimated that, a while ago, some early warning aircraft may already have been fitted with the fifth generation surveillance radar AN/APS-145. Acting as the key point associated with ground surveillance, it is then necessary to realize divided selections for reconnaissance in connection with this type of airborne surveillance radar. /41

Primary parameters associated with early warning aircraft are as follows: (1) E-2C cruising altitude is 6-9km. Cruising speed is 498km/hr. Curising time without refueling is 6-7hr. On board, there are 3 electronic equipment operating personnel. (2)

With regard to E-3A, cruising time is 8h. Cruising speed is 0.6M. Altitude is 8.8 - 9.4km. On board are 13 electronics operating personnel. When altitudes are 9km, it is possible to detect high altitude targets at 500-650km, low altitude targets at 300-400km, low altitude cruise missiles at 270km. It is possible to supply 30 minutes advanced warning, track 600 targets simultaneously, identify 200 targets, and handle 300-400 targets.

The parameters of early warning aircraft surveillance radars described above are as shown in Table 1.

预警机	E−2C	E−3A
监视雷达型号	AN/APS−138	AN/APY−2
工作频率(MHz)	425	S波段
功率	峰值1MW，平均3.8kW	MW级
工作比	3.8/1000	
天线增益(dB)	21.5	
波束宽度(°)	方位6.6，机扫360	方位0.72，机扫360
	俯仰20，不扫	俯仰3.5，电扫±15，±30
副瓣电平(dB)	−26	−50
数据率(显示次数/min)	6	6
重频	300Hz	超视距工作为低重频；高重频为三脉冲参差
波　形	固定线性调频压缩比13μs/220ns=59	有7个工作方式：PD、超视距、海用方式（窄脉冲）、无源方式（两架测向定位干扰源）等
检测距离(km)	370（对海上A−6攻击机）148～260（对地面A−6飞机）	

Table 1 Two Types of Early Warning Aircraft Surveillance Radar

Early Warning Aircraft	E-2C	E-3A
Surveillance Radar	AN/APS-138	AN/APY-2
Operating Frequency (MHz)	425	S Wave Band
Power	Peak Value 1MW Average 3.8kW	MW Level
Operating Ratio	3.8/1000	
Antenna Gain (dB)	21.5	
Beam Width (°)	Azimuth 6.6 Mechanical Scan 360 Pitch 20, Non Sweep	Azimuth 0.7 (Illegible) Mechanical Scan 360 Pitch 3.5, Electical Sweep ±15, ±30
Auxilliary Lobe	-26	-50 (Illegible)

(Illegible) Electrical Level (dB)		
Data Rate (Number of Displays/Min)	6	6
Repetition Frequency	300 Hz	Supervisual Matrix Operations Are Low Repetition Frequency. High Repetition Frequency Is Three Pulse Zigzag.
Wave Forms	Fixed Linear Frequency Modulation Compression Ratio 13μs/220ns=59	There Are 7 Operating Modes: PD, Beyond Line of Sight, Maritime Methods (Narrow Pulse), Passive Methods (Dual Direction Finding and Positioning of Jamming Sources) etc.

Detection Range (Km)	370 (Against Navy A-6 Attack Aircraft) 148-260 (Against Ground A-6 Aircraft)

Identification friend or foe systems on E2-C and E3-A are all MKX and MKX11. They operate in the L wave band. The typical parameters are as shown in Table 2.

Table 2
Typical Parameters Associated with MK Model Identification Friend or Foe Devices

	Query Device	Response Device
Frequency (MHz)	1030±0.(illegible)	1090±3
Polarization	Vertical	Vertical
Pulse Width (μs)	0.8±0.18	0.45±0.1
Pulse Set Repetition Frequency (Hz)	300-400	
Output Power (kW)	1-1.5 (Peak Value)	0.5 (Peak Value)
Antenna Rotation Speed (rpm)	6-15	
Beam Width (°)	2.8-7.0	

1.2 Electronic Warfare Aircraft and Combat Aircraft Carrying Self-Defense Type Jammers

At the present time, the electronic warfare aircraft which the U.S. primarily uses in combat are EF-111 and EA-6B. The main equipment is ALQ-99E high power jammers. Frequency coverage ranges are 0.03-18GHz. Antenna gains are 13dB. Jamming powers

are greater than 1kW (continuous wave power). Jamming power densities are 1-2kW/MHz. These two types of jamming planes are primarily used in long range support jamming (SOJ) and screen jamming following units (ESJ).

In combat aircraft, such primary low power jamming systems as ALQ-137, ALQ-165, and so on, are all dual mode. That is, they are capable of laying down continuous wave noise jamming. They are also capable of laying down deception jamming. The ALQ-137 frequency coverage range is 0.7-18GHz. Peak value power is 58-63dBm. Operating ratios are 5%-10%. Antenna gains are 9dB. This type of jammer is primarily used for self-defense on combat aircraft.

1.3 Tactical Applications of Aerial Jamming

In recent years, the jamming tactics which the U.S. has opted for the use of in many wars can be summarized in the several types below:

(1) Long Range Support Jamming (SOJ). This is specialized electronic warfare aircraft, outside the defensive zones associated with enemy weapons systems (approximately 150km), flying in ellipses or figure 8's at altitudes of 5-10km. When this type of jamming tactic is applied, carrier aircraft implement jamming in airspace far away from weapons system kill zones. Moreover, jamming powers are very great. Jamming results are obvious. /42

(2) Entourage Screen Jamming (ESJ). This is flown by attack aircraft formations. Among these, there is a specialized electronic warfare aircraft following along to implement jamming in order to screen attacking aircraft formations entering into actual defensive zones for combat.

(3) Self-Defense Type Jamming (SSJ). Attack aircraft carry their own jamming equipment. During attacks, they lay down jamming to protect themselves.

(4) Close Range Support Jammng (SFJ). By deploying specialized electronic warfare planes in front of attacking aircraft formations, fly formation together with attacking aircraft and screen the offensive of the attack aircraft. When targets are met with in flight, electronic warfare aircraft leave formations and continue laying down jamming at high altitudes in order to screen attacks of attack planes against targets and to depart the target area. As far as this type of jamming tactic is concerned, it normally requires entering into the range of enemy

air defense missiles. Therefore, it is necessary to possess comparatively strong self-defense jamming capabilities.

(5) Dropable Type Jammer Tactics (EPJ). After being dropped, jammers are capable of being three types--apex, near air, and ground. They are used in order to screen attacking aircraft entering into enemy defensive zones to attack targets. The frequency ranges covered by one time drop type jammers are comparatively small (a maximum of one wave band). Powers are also very limited (normally, only a few watts to a few hundred watts). Operating times are generally 5-10 minutes. Maximum is an hour.

(6) Mutual Support Jamming (MSJ). This is two or more aircraft flying in aerial formation going through mutual coordination and mutual support to carry out joint or alternating jamming in order to create jamming effects which no single aircraft could achieve.

Aerial jamming tactics are none other than the several types described above. At the present time, U.S. stress is on enlarging jamming powers. The power of ALQ-99E is already not the strongest. At the present time, jammers are in the midst of developments which have jamming powers 1-2 orders of magnitude higher the jamming powers of EF-111A's and EA-6B's. Besides this, there is also a need to strengthen the development of very effective, ingenious jammers and one time drop jammer decoys.

2 BASIC IDEAS ASSOCIATED WITH RECONNAISSANCE EARLY WARNING AIRCRAFT AND JAMMING PLATFORMS

The presupposition associated with carrying out attacks against early warning aircraft and jamming platforms is the capability to carry out aerial reconnaissance and positioning against them. Due to the fact that both of them are electromagnetic radiation carriers, this will then provide the conditions for the ground to carry out electromagnetic reconnaissance. Of course, the primary radiation sources associated with early warning aircraft are surveillance radars. Radiation sources associated with jamming platforms are the jammers. The former are pulse signals. The latter are continuous wave jamming signals. Respectively, the two of them have different characteristics (see Table 3).

Table 3 Different Characteristics of Radiation Sources Associated with Early Warning Aircraft and Jamming Platforms

Early Warning Aircraft Surveillance Radars	Airborne Jammers
Pulse Signals	Continuous Noise Jamming Signals
Antenna Beams Narrow. Auxilliary Lobe Levels Low.	Antenna Beams Wide. Auxilliary Lobe Electic Levels High.
Antennas Present Scanning Operations Status.	Antennas Point at Fixed Targets.
Multiple Signal Characteristic Parameters.	Signal Characteristic Parameters Few.

If use is made of ground to air or air to air antiradiation missiles (ARM) in order to attack early warning aircraft and jamming platforms, then, ground reconnaissance equipment must possess capabilities associated with the ability to reconnoiter early warning aircraft and jamming platforms at the same time.

If air to air ARM are used in order to make attacks, the combat process is to rely on surface reconnaissance systems to do rough guidance. Once air to air ARM carrying planes take off, then, autonomous positioning of targets is done by the carrying aircraft. In this way, it is possible to very, very greatly simplify and reduce the performance requirements with regard to surface reconnaissance systems--in particular, with respect to range calculation requirements. Direction finding and frequency measurements will be combined into one. Early warning aircraft positioning and jamming platform positioning will be combined into one. In conjunction with this, option is made for the use of single station positioning techniques, taking direction finding, frequency measurements, and target differences as the main things.

The basic framework associated with reconnaissance systems makes use of methods of direction finding involving no pitch scan and mechanical azimuth scanning. Use is made of channelized receivers to do frequency measurements. Use is made of signal processing technologies in addition to specialized system software to carry out target differentiations, range calculations, as well as threat assessments, selection of attack targets, and so on.

3 SURFACE RECONNAISSANCE SYSTEM DESIGNS

3.1 Direction Finding Designs

Early warning aircraft frequency bands are 425MHz (E-2C) and S wave band (E-3A). At the present time, primary use is made of surveillance radars associated with these two types of early warning aircraft. In the future, there will, undoubtedly, be the appearance of other wave bands. Moreover, jammer wave bands are, by contrast, comparatively wide. Those normally used, for the most part, are L wave band, S wave band, C wave band, X wave band, and so on. Expansion jamming wave bands even exist toward the two sides. With a view to the situations described above, as far as reconnaissance system frequency bands are concerned, option should be made for the use of frequency bands associated with 0.4-12GHz.

With regard to this type of frequency band, as far as option being made for the use of phase control array antennas is concerned, this is obviously unconditional. Therefore, in terms of pitch, there is also no way for one dimensional electrical scanning. Calculations on this basis are as shown in Fig.4.

斜距(km)	目标高度(km)	天线仰角(°)
400	6~10	0.86~1.43
150	6~10	2.3~3.8
50	6~10	6.9~11.5

Fig.4 Relationships Associated with Slant Range and Target Altitude as Well as Antenna Angles of Elevation

Slant Range (km)	Target Altitude (km)	Antenna Angle of Elevation (°)
400	6-10	0.86-1.43
150	6-10	2.3-3.8
50	6-10	6.9-11.5

波 段	方 位	俯仰*
X 波段	1.5°	6°
C 波段	3°	6°
S 波段	6°	12°
0.4~1.5GHz	6°	12°

Fig.5 Various Wave Band Beam Widths

Wave Band	Azimuth	Angle of Elevation*
X Wave Band	1.5°	6°
C Wave Band	3°	6°
S Wave Band	6°	12°
0.4-1.5GHz	6°	12°

*Opting for the use of complex feed source composite technologies, the required 6° and 12° are achieved.

Generally speaking, the ranges associated with self-defense type jamming aircraft are comparatively close. However, altitudes are on the low side. Besides this, early warning aircraft ranges are at least beyond 200km. As a result, antenna vertical beam width is fixed as 4°-5°. Azimuth beams are different on the basis of different wave bands. In the same way, vertical beams are also related to wave bands. Various wave band beam widths are seen in Fig.5. Antenna forms opt for the use of one joint parabolic surface antenna for the three wave bands S, C, and X. However, it is necessary to, respectively, opt for the use of different feed sources. L wave band and below (0.4-1.5GHz) use another antenna. This antenna and S, C, and X wave band antennas are installed back to back.

Azimuth angle measurement precisions are normally beam widths of 0.1-0.2. Basically, it is possible to satisfy requirements associated with fast positioning in regard to radiation sources after take off and to guide aircraft. The lowest wave band precisions are also capable of reaching 0.6°.

In this way, in X wave band and C wave band, current systems are capable of detecting targets beyond 100km at 10km altitudes. In S wave band, by contrast, it is possible to detect targets beyond 50km at 10km altitudes. Because the flight ranges of jamming aircraft are normally within 200km, obviously, vertical beam widths that are 3° are inadequate. Therefore, it is necessary to use multiple feed sources in order to increase vertical beam widths, making them reach 6°. Only then is it possible to detect targets out to 100km or more at altitudes of 10km.

If it is necessary to detect closer targets, this type of opportunity is generally quite rare. It is then possible to make antennas lift up 5°, and it is possible to detect targets beyond 50km at altitudes of 10km. Within 50km, it is generally self-

defense type jamming. Normally, flight altitudes are comparatively low. It is possible to detect them in all cases.

As far as reflector surfaces designed in accordance with C wave bands are concerned, 0.4-1.5GHz wave band antennas are capable of using microband array antennas. As much as possible, substrate materials opt for the use of dielectrics associated with high dielectric constants. Also, a number of auxilliary measures are added. It is possible to make antennas half their normal size. Due to being subject to influences associated with the curvature of the earth, antenna frames must be high. Only then is it possible to detect targets farther than 400km at altitudes of 6km.

In accordance with empirical formulae, slant range R(km)=4.12x $(H_t^{\frac{1}{2}}+H_a^{\frac{1}{2}})$ in calculations. In this, Ha is antenna height. Ht is target height. If R=400km and Ht=6km, then, Ha=385m. If Ht=9km, then Ha=5m.

From this, it can be seen that, if one wants to detect early warning aircraft, reconnaissance antennas require frames on high places. If jamming platforms are detected, due to the fact that the distances between are within 200km, antennas do not use high frames.

Antenna scanning speeds can be selected as 30 rpm. This is primarily used in reconnaissance and early warning aircraft surveillance radars. However, a data rate problem exists. With regard to the fact that jamming platform signals are continuous, there is basically no influence. At the present time, in view of early warning aircraft beam widths being 6°, repetition frequencies with regard to E-2C surveillance radars are then 300Hz. In 6° beam irradiation periods, it is possible to receive 10 radar pulses. Of course--besides making 360° scans--radars are also capable, on the basis of the requirements of the combat situation at that time, of making fan sweeps. In this way, data rates can also be improved.

3.2 Frequency Measurement Designs

Option is made for the use of channelized receivers to measure frequencies. Frequency measurement range is 0.4-12GHz. Instantaneous band width is 2-4GHz. Frequency measurement precision is 2-3MHz(r.m.s). Receiver sensitivity is -100-- -110dBm. Dynamic range is 60-70dB.

Due to the fact that powers associated with surveillance radars on early warning aircraft are MW level in all cases, therefore, despite the fact that ranges are very long, surface reconnaissance system detection signal powers are still very strong. In general situations, selections are made of P(illegible) = 60dBW, G(illegible) = 21.5dB, G(illegible) = 25dB, ■ = 10cm (E-3A), and R = 400km. Then, surface reconnaissance reception power is -47.54dBW. Of course, as far as jammer radiated powers are concerned, transmiting antenna gains in all cases are smaller than early warning aircraft. Wave lengths are also small. Therefore, in general situations, P(illegible) =

1000W, G(illegible) = 10dB, G(illegible) = 30dB, ■ = 3cm, and R = 200km. Then, surface reception power is -88.46dBW. From this, it can be seen that receiver sensitivities of -100dBW should be possible to satisfy. /44

Channelized receivers opt for the use of acoustic surface wave filter devices. Channel numbers are 400-800. In general situations, using time division methods, it is possible to operate in all frequency bands. In special situations, it is possbile to opt for operations within corresponding instantaneous band width frequency ranges (determined by war time situation).

3.3 Signal Processing and Expert System Software

Opting for the use of this type of reconnaissance system design, it is possible to realize full environmental reconnaissance. On the basis of currently existing accomplishments, we are capable of measuring the azimuth, frequency, jamming band width, and jamming power intensity associated with jamming sources. In conjunction with this, by analysis using these parameters described above, the tactical missions carried out by each jamming source platform are differentiated as well as ranges being calculated. At the same time, threat assessments are carried out with regard to all jamming source platforms in the space, selecting the first batch of targets which need to be attacked. With regard to early warning aircraft, we primarily measure their surveillance radar parameters. In conjunction with this, differentiation is carried out. Measurements of such things as azimuth and intensity require the coordination of certain signal processing technologies. Various frequency signal characteristics are extracted. It is then necessary to use computers in order for realization--including the application of expert system technologies.

Option is made for the use of Intel 520 multiple CPU systems. Generally, there is a requirement for 7 CPU boards. Among these, 4 units make real time signal differentiations associated with four wave bands. Two units do expert system operations. One unit does comprehensive display control.

Signal processing is capable of using 8096 single chip devices. One chip or more correspond to each wave band. These technologies are all comparatively easy to realize. However, range calculation value errors obtained in this way are relatively large. With regard to surveillance radars on early warning aircraft, because parameters are comparatively precisely specified, result errors associated with calculations are comparatively small. However, with respect to jamming platforms, due to the fact that multiple types of jamming powers and jamming antenna gains are also not clear, errors are naturally quite large. If errors are 6dB, ranges will then be off by a half. If air to air ARM's are used to make attacks, after take off from air to air ARM platforms, positioning is carried out autonomously. Requirements associated with this area will then

not be that high.

3.4 Communications Sections

Reconnaissance systems mainly establish communication relationships with command centers. By reconnaissance systems supplying command centers with information, command centers make decisions. In conjunction with this, aircraft are ordered to take off. Therefore, reconnaissance systems should, as much as possible, be close to combat command centers. In this way, it is possible to make use of digital transmission wire communications systems for realization. Once it is necessary to be far away from command centers, it is then possible to opt for the use of wireless digital transimission communication methods. Both of these can make use of technologies which are currently on hand.

4 CONCLUDING REMARKS

No matter whether option is made for the use of ground to air ARM or air to air ARM in order to attack early warning aircraft or jamming platforms--even to the point of going through means associated with the jamming of early warning aircraft surveillance radars--in all cases, it is not possible to separate from the effective support of ground reconnaissance systems. As a result, with regard to ground reconnaissance associated with early warning aircraft and jamming platforms, they are indispensable systems in wars of national territorial defense at the present time and in the future. Adequately serious attention should be given to them. In conjunction with that, development should be begun immediately.

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COMBAT AIRCRAFT INFRARED RADIATION CHARACTERISTICS AND THEIR INFRARED COUNTERMEASURE AND SUPPRESSION TECHNOLOGIES

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Translation of "Zuo Zhan Fei Ji De Hong Wai Fu She Te Xing Ji Qi Hong Wai Dui Kang Yu Yi Zhi Ji Shu"; Astronavigational Electronic Countermeasures, No.2, 1995, pp 5-10

ABSTRACT A simple introduction is made of medium and high altitude combat aircraft (fighters, bombers, early warning aircraft, and electronic warfare aircraft) infrared radiation characteristics, influences of atmospheric propogation on infrared guided missile detection of these infrared targets, airborne infrared countermeasures (alarm technology, infrared decoys, and jamming) as well as aircraft infrared radiation inhibiting technologies, and so on.

KEY WORDS Infrared radiation Infrared countermeasures Infrared alarm Infrared decoy Infrared suppression

1 INTRODUCTION

Infrared imagery guidance is the main stream in the development of photoelectric guidance technology in the period of time from now on. It possesses such characteristics as high guidance precision, good concealment properties, strong counter jamming capabilities, fire and forget, as well as the ability to select critical parts of targets to be attacked, and so on. As a result, since the 1970's, this technology has been a development focus of various major countries right along. In conjunction with this, there has been gradual application to antiwarship and antiaircraft missiles. Here, the primary research has been on the aerial targets and photoelectric jamming environments

associated with medium and high altitude infrared. It has involved infrared radiation characteristics of fighters, bombers, early warning aircraft, and electronic warfare aircraft associated with combat in 5-20km air spaces. These infrared radiation characteristics are compared to background infrared radiation properties. The combat aircraft described above are capable of carrying infrared countermeasures equipment as well as opting for the use of infrared inhibiting technologies, and so on, and so forth. In all cases, these are one of the important foundations associated with infrared imagery guidance weapon system development.

2 INFRARED RADIATION CHARACTERISTICS OF COMBAT AIRCRAFT

Infrared radiation characteristics of combat aircraft (primarily refering to jet type aircraft) are an important parameter that must be grasped when designing aircraft. They are also a key parameter which must be understood by personnel designing infrared imagery guidance ground to air missiles using aircraft as targets. Therefore, general characteristics associated with aircraft infrared radiation are studied. In conjunction with this, in theoretical terms, the calculation of aircraft infrared radiation intensities as well as the status of their distributions is very important.

Generally, use is made of experimental and theoretical approximation methods in order to calculate aircraft infrared radiation fields. Costs associated with experimental methods are expensive. Therefore, ususally, option is made for the use of methods associated with research in theoretical terms on aircraft infrared radiation mechanisms to precisely specify aircraft infrared radiation characteristics.

2.1 Aircraft Infrared Radiation Characteristics

Aircraft infrared radiation sources lie in reflections associated with radiation coming from the aircraft itself and environmental radiation. The primary radiation sources include: engine jet sheaf, aerodynamic fuselage heating, other components putting out heat and giving rise to radiation, as well as reflections and scattering following direct irradiation by sunlight. The remainder can be seen as secondary radiation sources. Among these, energies associated with free radiation account for 0.001% of total engine energy. It can be seen that most of the energy is moved out into environmental media by the use of such methods as convection layer diffusion, and so on.

Autoradiation characteristics associated with various radiation source parts in jet aircraft are as shown in Table 1. /6

Table 1 Table of General Status for Infrared Radiation Characteristics Associated with Various Parts of Jet Aircraft

Radiation Source Site	Infrared Radiation	Wave Band (μm)
Engine		
Jet Port Metal Radiation	Gray Body Radiation (Specific Radiation Rate Taken as ϵ=0.90)	3-5
Jet Tube Jet Flow Radiation	Combustion Gas Heat Radiation (CO2,H2O)	2-3,4-5
Aerodynamics Make Aircraft Skin Friction Produce Radiation	Aerodynamic Heating Radiation	3-5,8-14
Reflection and Scattering After Direct Exposure of Fuselage to Sunlight	Reflection After Sunlight (Background) Irradiation	2-3
Engine, Fuselage Equipment Heat Conduction Leads to Aircraft Outer Surface Radiation		

2.2 Infrared Radiation Status of Engine Sites

The main infrared radiation sources associated with aircraft are all related to engines. Engine thermal components radiate. In particular, hot metal parts associated with tail jet tubes are primary thermal radiation sources, producing high radiation rate gray body radiation. Maximum radiation values are in approximately the 3-5μm wave band. Jet tube jet gas flow radiation refers to tail plume radiation associated with exhaust combustion gases. The radiation distiribution is not continuous.

The primary radiations produced are in the CO2■H2O 2.7μm and CO2 4.7μm wave bands.

2.3 Aerodynamic Heating Radiation

Aerodynamic heating radiation refers to heating due to aerodynamic forces, temperature rises on the surface of fuselages, and the thermal radiation produced. During low speed flight, the effects of aerodynamic heating are not too obvious. There are only some influences on stagnant zones associated with the nose area. However, speaking in terms of high speed aircraft, this type of influence is very clear. In particular, when Mach numbers reach 2 or higher, aerodynamic heating temperatures are very high. Radiation peak values are, respectively, in the 8-14μm and 3-5μm ranges. Radiation intensities are determined by skin temperature. Maximum tempertures associated with aerodynamic heating are determined by outer shell laminar flow stagnation temperatures.

$$Ts = To\ [1+■(V-1)/2■M2]$$

In the equation, To is ambient atmospheric temperature (K), ■ is restitution coefficient. Their values are determined by the status of gas flow movements pressed close to skin surfaces. During laminar flow, ■ = 0.85. During turbulent flow, ■ = 0.90. V is specific heat ratio, that is, the ratio of constant pressure molar heat capacity and constant capcity mol. M is aircraft local Mach number.

When aircraft speeds reach M = 2-3, tempertures are capable of reaching 500K or higher. When it is possible to see aerodynamic heating, skin infrared radiation is quite intense. Taking medium and close range missiles as examples, their surface temperatures are capable of reaching 300-600K. Wave lengths are 4.83-9.66μm.

2.4 Reflection and Scattering Radiation Associated with Sunlight on Fuselages

Due to the fact that aircraft skins are mostly metal, it is necessary to consider reflected and scattered radiation from sunlight. Speaking in terms of surface skins with smooth finishs, as far as reflection factors and material optical properties are concerned, the status of surfaces (for example, paint layers) and reflection angles are related. With regard to sunlight shining on fuselages--besides most of it, which is reflected--there is also a part which is absorbed by the skin, causing skin temperature to go up and increasing radiation from the skin itself.

The reflection of sunlight by fuselages is a comparatively complex phenomenon. The magnitude of reflected radiation is primarily determined by (1) the relationships between sunlight, aircraft, and detection devices; (2) the configuration of reflecting surfaces and reflection factors; (3) whether the refelction properties of surfaces are diffuse reflection or mirror surface reflection, as well as (4) aircraft background radiation.

3 COMPARISON OF TARGET AND BACKGROUND INFRARED RADIATION CHARACTERISTICS

Target and background infrared signal characteristics are subject to control by intervening atmosphere. Aerial targets produce heat from solar irradiation and internal heat sources, and, because of thermodynamic heating radiation (related to Mach speed), aircraft give rise to skin temperture changes. What infrared imagery guidance sensors on ground to air missiles detect is the temperature differentials seen between targets and backgrounds, determined by the infrared penetration rates and emissions. In tactical applications, it is necessary to be able to detect and differentiate between aerial targets located at places several tens of kilometers away. /7

Infrared imagery systems are ones which discover targets through the temperature differences between targets and backgrounds. Due to the fact that the transmission rates of the atmosphere within an 8-14μm wave band are very low, therefore, the equivalent radiation temperature associated with the background sky is very low. Moreover, within the wave band in question, the atmosphere possesses very high transparency. Due to friction and engine heat diffusion between high speed flying

objects and the atmosphere, aircraft themselves will possess very high temperatures. Even if aircraft opt for the use of certain infrared stealth measures, aircraft in a monotonic sky background will still be an obvious infrared radiation target.

Sunlight spectra radiation densities are normally at 0.5μm. Although their emission energies are 98% in a 0.15-3μm wave band, and their effective temperatures follow along with increases in wave length and go down, at 11μm locations, however, temperatures are still able to reach 300K black body. As a result, speaking in terms of infrared imagery guidance associated with 8-14μm wave bands, the sun is still a source of interference.

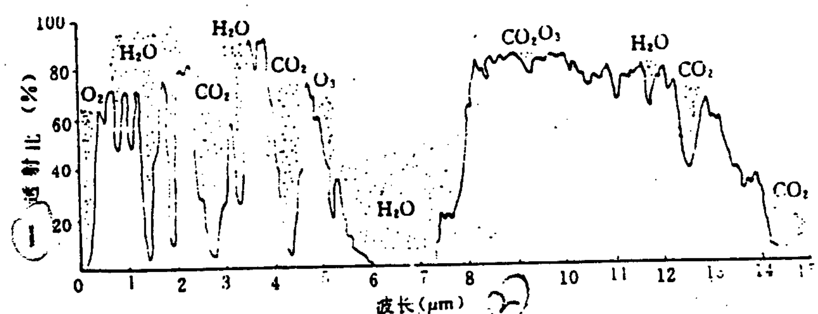

图 1 大气对红外辐射的透射光谱

Fig.1 Transmission Spectra Associated with the Atmosphere Versus Infrared Radiation (1) Transmission Ratio (2) Wave Length

Looking from the point of view of transmission spectra associated with the atmosphere versus infrared radiation, when infrared radiation is propogated in the atmosphere, the water vapor, carbon dioxide, and so on, in the atmosphere give rise to comparatively strong absorption bands with regard to it. The absorption bands in question are related to infrared radiation wave lengths. These gaps between bands form "infrared windows". Among them, the widest is 8-13μm. Please see Fig.1.

4 ANALYSIS OF AIRBORNE INFRARED JAMMING TECHNOLOGY

Airborne infrared jamming technology and equipment primarily include infrared alarm systems associated with the detection of infrared guidance guided missiles, infrared decoys, infrared jammers, blinding type jamming, destruction type jamming, as well as making use of the sun and other such radiation sources to carry out other similar tactical maneuver measures.

4.1 Infrared Alarm Devices (Systems)

What the level of airborne infrared alarms is relates to whether or not aircraft are able to adopt effective active and passive infrared countermeasures and avoid meeting with attacks by infrared guided missiles. Speaking in terms of attacking ground to air missiles, it is then necessary, beginning from how infrared radiation is inhibited in and of itself, to use shrinking of airborne infrared alarm device early warning time to achieve effective attacks on targets.

Infrared alarm technology is going through reception and analysis of infrared radiation associated with such targets themselves as aircraft, missiles, and so on, in order to actualize alarms. Early infrared alarms made primary use of instantaneous spectra associated with target infrared radiation (for example, the sharp peaks produced by flame tongues when missiles are fired). Wave length and time period characteristics were used to make differentiations. Methods were simple. Recognition rates were low. Moreover, false alarms were high, and practical utility was bad. Alarm devices developed afterwards--through opting for the use of such measures as new technologies, new components, and so on--gradually lowered false alarm rates, and recognition capabilities improved. At the present time, comparatively advanced infrared alarm devices all possess automatic alarm sounding, automatically controled release of infrared decoys, and functions for the implementation of infrared jamming. Alarm devices primarily detect the tail flames (3-5μm) put out at the jet tube ports associated with the main section engines of infrared guided ground to air and air to air missiles as well as infrared radiation (8-14μm) associated with high speed missile body aerodynamic heating.

U.S. active service infrared alarm devices (systems) and their platforms primarily include:

AN/ALR-21	B-52G/H (Air Force)	AN/AAR-37	P-3C (Navy)
AN/ALR-23	F-111 (Air Force)	AN/AAR-38,44	F-15 (Air Force)
AN/ALR-34	F-111 (Air Force)	AN/AAR-47	Tactical Aircraft

(Air Force and Navy)

In actual applications, due to the fact that the effective ranges of infrared alarm passive detection systems are limited, they are not capable of supplying adequate early warning times and accurate range parameters. Moreover, it is not possible to operate under bad metrological conditions. Therefore, more advanced infrared alarm systems normally require the use of combinations with other detection means (for example, active type Doppler radar alarm systems). For instance, combined active and passive silent attack missile alarm systems (MAWS) are then capable of carrying out comprehensive detection with regard to various types of identification characteristic information (thermal radiation, electromagnetic, and aerodynamic characteristics) which are possessed by infrared imagery guided missiles. Despite the fact that, at the present time--with regard to missile infrared radiation and electromagnetic characteristics--it is already possible to adopt various types of stealth technology, and, with the addition of effective suppression and camoflage, make alarm devices using passive thermal search and active radar search be influenced to a certain level, at the present time, however--with regard to aerodynamic characteristics of flying objects--there are still no effective camoflage or inhibiting measures. /8

4.2 Infrared Decoy Rounds

As far as active infrared decoy rounds which are used in creating a false target are concerned, they are capable of being launched from aircraft--drawing off air to air and ground to air missiles, making them lose (illegible) tracking of targets, thereby reaching the objective of protecting aircraft targets. The structure of infrared decoy rounds is simple. Costs are low. It is also possible to carry many of them, and (illegible) many. They are, at the present time, the primary means of coping with infrared guided missiles. Normally, infrared decoy rounds make use of magnesium-polyfluoroethylene, magnesium-aluminum-ferric oxide, as well as magnesium-sodium nitrate, and so on, to act as light emiting materials. The infrared radiation wave length is 1.8-5.4μm. Combustion time is 5-30s. This is just in line with aircraft engine infrared radiation. Most fighters and bombers are fitted with release devices on the tails of the aircraft.

U.S. Air Force active service airborne infrared decoy rounds and platforms fitted with them include:

AN/ALA-17 B-52,FB-111 (Air Force) AN/ALA-34 B-52 (Air Force)

AN/AAS-26 B-52G (Air Force)	MK46/47 A-4,6,7, F-4,14 (Air Force and Navy)
MJU-7B A-7, F-15(Air Force/Navy)	MJU-8 A-6,7 (Navy)
AN/ALE-20 B-52, F-15, EB-66 (Air Force)	Lacroix Series F-16 (Air Force)

With regard to comparatively advanced active service airborne infrared decoys, most of them are point source model high power tracer rounds. They are capable of simulating engine jet plume thermal radiation. With respect to point source single wave band infrared homing guidance heads, they possess relatively good jamming results. However, with regard to multiple wave band infrared imagery guidance heads, they are then not capable of proving effective. As a result, it is necessary to develop new models of airborne infrared decoy systems.

Development trends associated with infrared decoy rounds are to expand infrared radiation wave length ranges, and, in conjunction with this, make infrared radiation characteristics approach more closely the targets being protected. (1) In terms of spectra, developing capabilities to use effective methods to produce new heat generating materials to cover wide spectra. For example, adding appropriate light generating materials to tracer round constituents or using combustion constituents from the protected targets in order to produce selective radiation spectra or corresponding spectral characteristics or to raise radiation energies associated with corresponding spectral zones. (2) Developing large load tracer rounds in order to form infrared jamming clouds with comparatively large areas (as area source model decoys) or directly making use of fuel jet combustion to form simulated jamming clouds associated with relatively large areas. (3) From aerodynamic characterisitcs, opting for the use of a set of elongated shrouds capable of wrapping around tracer round combustion ends to make decoy radiation energies directly follow tracer rounds or opting for the use of a jet nozzle of appropriate dimensions to make exhaust speeds and free flows match up with each other so as to reduce aerodynaminc decay with regard to decoy output energies. Besides this, it is also possible to opt for the use of effective aerodynamic designs to make decoy flight in the air stable, and, in conjunction with this, maintain flight tracks an optimum distance from targets.

A kind of dropped type "fly along" decoy called Loraler is just in the midst of development. It uses rocket thrust. After it is launched out, it is capable of leading away infrared guided missiles to follow it and leave the protected aircraft. This

type of decoy sticks close to the aircarft in flight when it is just launched, positioning itself in the same field of view as the aircraft. Its infrared characteristic signals are similar to the aircraft. When it flies along an appropriate trajectory, it then leads attacking infrared missiles away. There is also a type of trailed infrared decoy. The infrared characteristics it produces are very similar to the infrared characteristics associated with large model aircraft. Use is made of a combustion chamber in order to heat radiation tubes. Fuel mixtures and emission tube paint layers are all capable of simulating the production of infrared characteristics which are consistent with aircraft. On the basis of reports, France has also developed a type of infrared decoy round which uses liquid titanium tetrachloride and pyrotechnics to act as infrared decoy round heat sources. It is capable of producing 8-14μm infrared radiation smoke clouds.

4.3 Airborne Infrared Jammers

Airborne infrared jammers are normally composed of high energy infrared spectral sources, connect-disconnect switches, modulators, and optical systems (equivalent to transmission antennas). The jamming view field is located within the threat alarm field of view. They are capable of simulating infrared radiation energies much higher than aircraft engines and other heat generating parts. In conjunction with this, broad wave band, wide field of view infrared radiation energies are emitted toward the directions of attacking missiles. The modulated infrared wave lengths must be within missile infrared guidance wave bands. In this way, two infrared "hot" targets will appear within guidance head fields of view. One is real. One is false.

After going through modulation board processing, entry is simultaneously made into tracking circuits, tricking the missile away from the real target. This type of jammer primarily jams infrared homing guidance missiles associated with 1-3μm and 3-5μm wave bands. /9

Early infrared jammers were primarily applied to helicopters and low speed fixed wing aircraft. After the 1980's, option began to be made for the use of technologies under the comtrol of microcomputers and associated with variable jammer pulse speeds, forms, and encoding. In conjunction with this, development was done of infrared jammers associated with directionally transmited jamming pulses. Performance experienced comparatively great improvements, and, in conjunction with that, applications were made to fighter aircraft one after the other. At the present time, most of the infrared jammers that have already been fitted

make use of noncoherent light sources. Wave lengths are only 0.4-1.5μm. Infrared jammer models of U.S. active service equipment, types, and equipment platforms include: AN/ALQ-107 Cesium Vapor Lamps A-3,4M,6,7,8 (5 types of attack

aircraft all together) AN/ALQ-123 Cesium Vapor Lamps A-4,6,7 attack aircraft, F-

4,14,15,16 fighters
AN/ALQ 132 Fuel Model A-10 attack aircraft, C-130

AN/ALQ 140 Electrothermal Type F-4 fighter

As far as new active infrared jamming technology is concerned, alterations have been made in missile deception jamming mechanisms associated with jamming point source modulated infrared homing in the past. Option is more made for the use of high power suppression type jamming. Through the production of large jamming/signal ratios, it is possible to make imagery guidance head detection devices operate in nonlinear saturation zones. But, it is not possible to form clear target images, even to the point of causing imagery elements to break down. It is said that fixed time pulses transmited by ALQ-123 model jammers are only capable of making missile infrared guidance heads lose effectiveness.

5 INFRARED RADIATION INHIBITING TECHNOLOGIES

Speaking in terms of aircraft radiation sources with regard to missile infrared guidance systems, they are nothing else than their signal sources. Aircraft can only adopt effective measures in order to inhibit infrared radiation. Only then is it possible to increase their own survivability. Generally describing the relevent materials, the infrared radiation inhibiting measures which aircraft opt for the use of primarily include the three areas below.

5.1 Lowering the Amount of Heat Dissipated by Aircraft Structures and Parts in Order to Reduce Radiation Energies

Engine tail jet ports are the strongest infrared sources exposed to the outside. In accordance with the Sitifen

(phonetic)-Boltzmann law, $W=\blacksquare\sigma T4$, it is possible to obtain radiation energies associated with objects. Here, $\blacksquare$ is the object radiation rate. Its material properties, geometrical configuration, and temperature are related. T is temperture K. σ is the constant 5.67x10-12 W/cm2. It is possible to see that, when temperature varies, radiation power also varies correspondingly. When there is no drop in temperature, engine jet nozzle radiation is primarily concentrated in the 3-5μm wave band. After temperature changes, the range of this wave band will be exceeded, causing detectors opting for the use of lead sulfide and even antimony not to play a role. Missiles have difficulty acquiring targets. It is possible to see that temperature drops and heat diffusion are critically important with regard to aircraft. Concrete measures include the following.

(1) Avoid opting for the use of afterburning. For example, B-2's and F-117A's often opt for the use of subsonic flight without afterburning.

(2) Set up engine closed loop cooling circuits to make the amounts of heat associated with heated air be carried by fuel tank fuel.

(3) Install additional sleeve shielding on engines to lower radiation temperatures.

(4) Opt for the use of liquid nitrogen to carry out cooling of engines--for example, the F-117A.

(5) Opt for the use of infrared inhibiting systems to carry out secondary temperature drops with regard to engines--for example, the AH-64 armed heliopter is capable of making temperatures drop from 590°C to 150°C.

(6) Use cooling gases to lower temperatures on engine jet tube part surfaces.

(7) Opt for the use of two dimensional jet tube technologies, making hot gases flowing out of jet tubes rapidly mix with the atmosphere. It is possible to filter out 90% of infrared radiation. That is equivalent to shortening the infrared detection range 45%--for example, the F117A.

(8) Opt for the use of turbofan engines with high conduit ratios. Use outside conduit cold air to cool hot air flows coming out of inside conduits, lowering jet tube temperture.

(9) As far as intake passages are concerned, set up special open slit damper plates in order to absorb air flows associated with the top of wing surface layers. Use adequate cold air to cool engine exhaust gases--for example, the B-2. /10

5.2 Lowering Infrared Radiation Energies

Engine combustion chambers are the most basic infrared source. Measures to lower their infrared radiation energies primarily include the following.

(1) Improve structural design. Concrete methods include ((1)) installing infrared damper plates on jet nozzles (for example, the Soviet Su-15 attack plane); ((2)) fuselage and tail surface sections covered with metal plates in order to reduce radiation (for example, the B-2 and F-117A); ((3)) opting for the use of large diameter S shaped air intakes and special shaped jet tubes. It is possible to make jet tube gas flows fast and lower in temperature, reducing radiation energies and altering infrared radiation wave lengths; ((4)) B-2 aircraft engine jet nozzles are placed in front of the tail surfaces. Tail jet flows pass the rear fuselage and are shot backward. Radiation energies are greatly reduced due to sheilding. ((5)) Engines opt for the use of new model atomizing nozzles to make fuel burn fully, reducing the amount of exhaust smoke. ((6)) Utilization is capable of making thrust revolve in direction or jet tubes reverse direction. They are capable of making jet flame minimal in detected directions.

(2) Utilize counter radiation materials. ((1)) On engine jet tubes, application is made of carbon fiber reinforced composite materials and ceramic materials. ((2)) On engine jet nozzle tail cone metal surfaces, spray paint materials with low emission rates or radioactive isotope coatings. Radiation excited during combustion processes makes the ambient air produce ions and absorb infrared radiation.

(3) Add radiation inhibiting additives during combustion. ((1)) Chloro-fluoro-sulfate additives are put into B-2 aircraft engine fuel to cause jet tube gas flow particle dimensions to reduce, lessening infrared radiation. In conjunction with this, radiation spectra change. ((2)) Make use of gaseous sols in order to shield engine tail plumes, reducing infrared radiation. For example, spraying out such epispastic foaming materials as polyethylene associated with metallic oxide particles of 1-100μm, phenol aldehyde resins, and so on, together with engine combustion materials in gas flows. After cooling, atomization forms particle suspensions. ((3)) Or, use materials which are easily ionized, such as, metallic powders containing tungsten, sodium, potassium, cesium, and so on, and spray them into engine tail combustion. High temperature heating and ionization form plasma zones. These have very strong reflecting effects on infrared radiation, forming a gaseous sol infrared shielding

layer around tail jet flows. It is possible to make infrared radiation attenuate to around 1/80. The biggest characteristic of gaseous sols is that their spectral coverage range is wide. Reflective effects are very good against all of visible light, infrared, microwaves, and so on. When they are subject to electromagnetic irradiation, the resulting effects are even better.

5.3 Attenuation of Radiation Created by Aerodynamic Heating

In order to lower air friction with fuselages--primarily leading wing edges, forward air intake edges, and the two walls--leading to skin temperature rises, heat absorbing insulating paints are applied to skins to inhibit aircraft surface temperature increases so as to reduce infrared temperature rise radiation. It is said that ATB bombers opt for the use of this type of method, causing 90% of heat amounts to be inhibited.

With regard to materials which prevent reconnaissance and detection of intermediate infrared and far infrared radiation, there is a requirement to be able to simulate background thermal radiation or cover target thermal radiation. The difficulty of this is comparatively great. Internationally, it is still being studied. The materials which are chosen for use are capable--drawing lessons from counter thermal infrared camoflage technologies such as foam plastics--of using spray paints or adhesives to make surface temperatures and background temperatures consistent, creating thermal infrared blindness. Whether or not this type of material is capable of being applied to high speed jet aircraft still remains to be demonstrated.

6 CONCLUSIONS

(1) Combat aircraft flying at high speeds in a monotonic sky background are an obvious infrared radiation target.

(2) As far as infrared alarm devices, infrared decoy rounds, and infrared jammers in active service are concerned, the majority are designed with a view to aircraft engine tail jet nozzle and tail plume design. Very few involve 8-14μm aerodynamic heating skin radiation.

(3) With regard to infrared radiation inhibiting measures as well as the application of such heat absorbing and insulating materials as skin paints and so on, there will be certain or

comparatively large influences on infrared guidance technologies.

However, no matter what kind of changes there are, aerodynamic heating of high speed aircraft or missiles giving rise to 8-14μm skin radiation is, by contrast, very difficult to avoid.

(4) Seen from the point of view of development, this article has not talked about radiation models of smoke screen rounds. It only has good prospects for resolving the two great difficulties of how to rapidly release and protect high speed aircraft. Another matter is nothing else than trailing or infrared decoys becoming one of the primary pieces of equipment associated with infrared countermeasures from now on.

CONTINUOUS WAVE DIRECTION FINDING TECHNOLOGIES ASSOCIATED WITH PHASE DISCRIMINATION METHODS

Shen Lan

Translation of "Jian Xiang Fa Lian Xu Bo Ce Xiang Ji Shu"; Electronic Countermeasure Technology, No.3, 1995, pp 8-12

[ABSTRACT] This article puts forward a type of phase discrimination CW direction finding system which resolves comparatively well the shortcomings associated with amplitude comparison methods of CW direction finding. The direction finder system in question is capable of appropriate use in systems with any number of antennas. Azimuth angle conversions are not related to numbers of antennas. Recievers directly measure CW signal azimuth angles. There is no need for computer operations.

Reaction speeds are fast. Direction finding precisions and direction finding sensitivities also reach comparatively high levels. Receiver structures are simple. They are easy to integrarte and calibrate for standardization. Detailed analysis is done of CW direction finding principles, and discussions are made of problems associated with capabilities for handling multiple signals. Finally, results associated witb 8 element antenna test prototypes are introduced.

KEY WORDS Phase discrimination Continuous wave direction finding receiver Multiple signal reception

0 INTRODUCTION

Continuous wave (CW) radars possess narrow transmission frequencies. Wave form handling is simple. There is no velocity fuzziness associated with target handling. Moreover,

transmission powers are small. Frequency division and concentration characteristics are high. Average powers and peak powers are basically equal. Such characteristics as these stand out. Applications get broader by the day. As a result, with regard to intercept of CW radar signals, it becomes more important every day. At the present time, our RWR equipment still has no CW direction finding functions, even though, in advanced ELINT systems, CW direction finding has also not yet become mature technology.

With regard to the primary difficulties associated with continuous wave radar direction finding, they are that continuous wave signals use video frequency circuits associated with blocking receivers. Option is made for the use of direct current coupling. Although it is possible to solve the blocking problem, severe direct current temperature drift, however, will cause direction finding accuracies to become very bad. For this reason, people have put forward going through a single blade multiple transimssion frequency switch to make high speed cut overs between the various receiving antennas. Option is made for the use of methods associated with single signal channel reception and alternating current coupling in order to resolve this. Azimuth algorithms still opt for the use of traditional amplitude comparision direction finding principles. Acting as pulse control direction finding systems--although amplitude comparision methods are mature--functioning as continuous wave direction finding systems, they still await improvements. For instance, algorithms are complicated and various. Systems associated with different numbers of antennas and azimuth algorithms are, respectively, different. Receivers are not capable of directly reporting CW signal azimuth angles. They are only able to provide signal amplitude information associated with various antennas. Azimuth angles are obtained after going through computer operations. Reaction speeds are comparatively slow. Receiver time sequence matching is rigorous, structures are complicated, and costs are relatively high.

This article puts forward a new type of CW direction finding method. It compensates to a comparatively large degree for the inadequacies of CW direction finding technology at the present time.

1 ANALYSIS OF DIRECTION FINDING PRINCIPLES

The method which is put forward is set up under the several basic concepts described below.

(1) The time periods that CW signals exist are comparatively

long. Being able to go through switches, only one signal channel is used to carry out reception and direction finding.

(2) During switch sequences and antenna matching, it is possible to take the signal amplitudes received from various antenna elements and combine them to convert into phase information. Direction finding becomes phase discrimination. /9

(3) CW receiver band width is relatively narrow. Direct detecton types can expect to achieve applicable sensitivities.

The basic system produced by CW direction finding reception is as shown in Fig.1.

The receiver operating process in question is roughly as follows. CW radar signals which are intercepted by antennas go through switch scanning reception, after which, wave detectors take the signal powers and convert them into amplitudes. Selective frequency amplifiers associated with the same frequencies as the switch scanning frequencies take fundamental amplitude wave forms and amplify them. Phase comparisons are carried out between these fundamental wave signals and the N frequency division signals associated with the basic amplitude, thus obtaining azimuth codes.

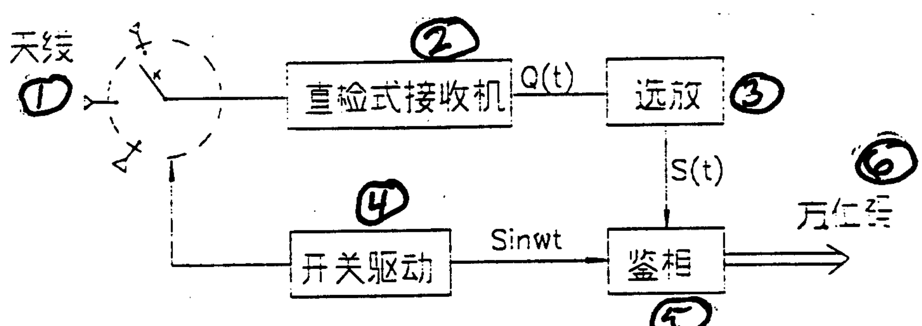

图1 连续波测向原理

Fig.1 Continuous Wave Direction Finding Principles (1) Antennas (2) Direct Detection Type Receiver (3) Selective Amplification (4) Switch Drive (5) Phase Discrimation (6) Azimuth Angle (Illegible)

We now make some simple analysis of the CW direction finding principles in question.

Assume that reception antenna arrays are composed of N antenna elements. Switches do periodic scanning of array

elements. The time period associated with each single antenna element lead is T/N. In this way, signals received by a certain single antenna element have wave forms, after being subject to wave detection, which are capable of being approximately described by the use of the functions below.

$$Q_n(t) = K_n F[t - \frac{T}{N}(n - 1)] \tag{1}$$

Kn is signal amplitude on antenna channels, and

$$F(t) = \begin{cases} 1 & (0 \sim T/N) \\ 0 & (T/N \sim T) \end{cases}$$

Then, the wave forms of all signals received by antennas after being subject to wave detection are

$$Q(t) = \sum_{n=1}^{N} K_n F(t - \frac{n-1}{N}T) \tag{2}$$

On the basis of Fourier series theory, letting f(t) be any periodic function, the period is T, and the angular frequency is ■ = $2\pi/T$. If the function in question satisfies Dilikelei (phonetic) conditions, it is then possible to take it and expand it into the Fourier series:

$$f(t) = A_0 \div \sum_{k=1}^{\infty} (A_k \cos k\omega t - B_k \sin k\omega t)$$

The coefficients in this are

$$A_0 = \frac{1}{T}\int_0^T f(t)\mathrm{d}t$$

$$A_k = \frac{2}{T}\int_0^T f(t)\cos k\omega t\mathrm{d}t$$

$$B_k = \frac{2}{T}\int_0^T f(t)\sin k\omega t\mathrm{d}t$$

When k = 1, the fundamental wave function then is $f_1(t) = A_1\cos\omega t + B_1\sin\omega t$

/10

In this $= C_1\sin[\omega t + \mathrm{tg}^{-1}(A_1/B_1)]$

$= C_1 \sin(\omega t + \Phi_1)$

$$C_1 = \sqrt{A_1^2 + B_1^2}$$
$$\Phi_1 = \mathrm{tg}^{-1}(A_1/B_1)$$
$$A_1 = \frac{2}{T}\int_0^T f_1(t)\cos\omega t dt$$
$$B_1 = \frac{2}{T}\int_0^T f_1(t)\sin\omega t dt$$

Due to the fact that Qn(t) can be expanded on the basis of a Fourier series as

$$Q_n(t) = K_n\left[A_{no} + \sum_{K=1}^{\infty}(A_{nk}\cos k\omega t + B_{nk}\sin k\omega t)\right] \quad (4)$$

Selective frequency amplifiers take fundamental wave signals and break them up. In conjunction with this, after amplification, the signals received by each antenna unit are then represented as:

$$\begin{aligned} S_n(t) &= GQ_{n1}(t) \\ &= GK_n(A_{n1}\cos\omega t + B_{n1}\sin\omega t) \\ &= GK_nC_{n1}\sin[\omega t + \mathrm{tg}^{-1}(A_{n1}/B_{n1})] \end{aligned} \quad (5)$$

In that case, signals recieved by recievers at this time go through selective frequency amplification, after which, the wave form function S(t) should be the sum of fundamental waves Sn(t) associated with signals revceived by each antenna, that is, the fundamental wave function associated with Q(t):

$$S(t) = \sum_{n=1}^{N} S_n(t)$$
$$= G\sum_{n=1}^{N} K_n C_{n1} \sin[\omega t + \mathrm{tg}^{-1}(A_{n1}/B_{n1})] \qquad (6)$$

On the basis of relationships associated with sum differences and products of trigonometric functions, it is possible to obtain

$$S(t) = Cs \sin[\blacksquare t + \Phi(Kn)]$$

In this Cs is normalized coefficient. $\Phi(Kn)$ is then S(t)'s initial phase angle. It is a function associated with Kn.

(6) The equations clearly show that, after superposition of sine waves with the same periods, signal periods do not vary. However, phases give rise to interference.

Normalized signal amplitude Kn is determined by azimuths reached by CW radar signals. Moreover, phases $\Phi(Kn)$ after fundamental wave interference are functions of (Kn). Therefore, taking S(t) and comparing it with fundamental amplitude sin■t, it is then possible to obtain $\Phi(Kn)$. After this phase goes through quantification, it is the CW signal azimuth code.

2 MULTIPLE SIGNAL DIRECTION FINDING CAPABILITIES

The question which is of great concern to us is that if there are two or more than two CW signals at the same time entering into receiver bands, what influence does that have on direction finding?

If the azimuth angles associated with radiation sources A and B are, respectively, ■A and ■B, from the analysis in the section above, it is possible to know that their signal functions after selective frequency amplification are, respectively

SA(t) = KA sin(■t + ■A)

SB(t) = KB sin(■t + ■B)

After superposition and synthesis, /11

S(t) = SA(t) + SB(t)

Using vectors, it is expressed as

S■■ = KA■■A + KB■■B

The results of direction finding at this time are changed from ■A or ■B to be phases associated with the sum of two signal vectors. Below, analysis is made of the relationships of direction finding errors given rise to by multiple signals and power magnitudes of the two.

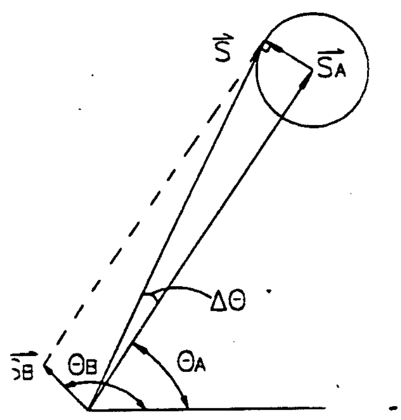

图 2 多信号测向误差分析

Fig.2 Multiple Signal Direction Finding Error Analysis

As is shown in Fig.2, when there is no signal B, signal azimuth is ■A. When signal A and signal B exist at the same time, measured azimuths become the phases (■A + ■■) associated with S. The azimuths of source A and source B are random. One end of S is distributed on a circumference associated with a radius equal to KB.

Obviously, maximum error occurs when S and the circumference are mutually tangential. At this time,

$$\Delta\theta_{MAX} = arc\ sin \frac{|\dot{S}_B|}{|\dot{S}_A|} = arc\ sin \frac{K_B}{K_A}$$

Let the powers of signals A and B be, respectively, PA and PB. Then, when PA - PB = 6dB, ■■(rms) = 8.7°. When PA - PB = 10dB, ■■(rms) = 5.3°. When PA - PB = 20dB, ■■(rms) = 1.7°. Clearly, when one has the appearance of multiple signals, azimuths should be vector sums associated with various target azimuths.

3 SYSTEM PROTOTYPE CONSTRUCTION AND TEST RESULTS

CW direction finding test prototypes opt for the use of eight element antenna reception designs, as shown in Fig.3. The primary technical indices associated with the prototype in question are as follows.

--Frequency range: 8-12GHz

--CW direction finding precision: 3°(rms) after frequency/azimuth calibration 5°(rms) frequency domain widened out

--Sensitivity: better than -60dBm

--Dynamic range: better than 40dB

--Azimuth coverage: 360°

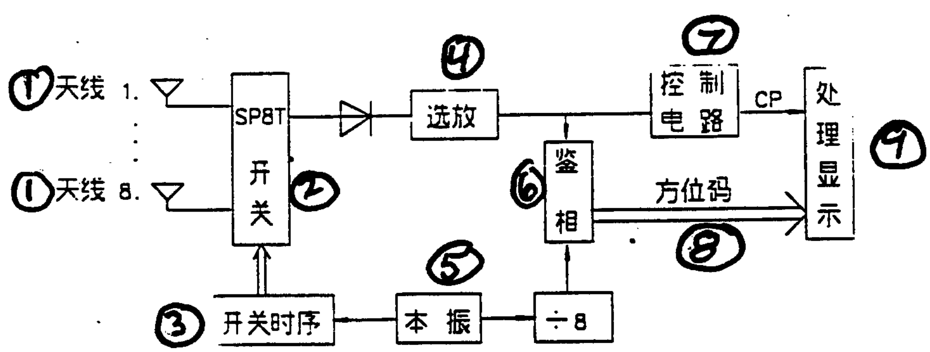

图 3 CW 测向接收机原理图

Fig.3 CW Direction Finding Receiver Schematic (1) Antenna (2) Switch (3) Switch Sequence (4) Selective Amplification (5) Basic Amplitude (6) Phase Discrimination (7) Control Circuitry (8) Azimuth Code (9) Processing Display

On the basis of test results, it is possible to reach the conclusions below with regard to this type of phase discrimination method CW direction finding system.

1. Band widths associated with selective amplification are narrow. Gains are high. Use is made of it to do main receiver amplification. Sensitivities for receivers as a whole are capable of reaching comparatively high levels. /12

2. In terms of basic principles, the signal amplitude received by each antenna must, in all cases, be a contribution to

doing direction finding. As a result, direction finding precisions should be high. Test results clearly show that this conclusion is correct. Direction finding precisions after going through frequency/azimuth calibration reach 3° (r,m,s). Direction finding precisions without having gone through frequency/azimuth calibration still reach 5° (r,m,s)--better than the levels associated with amplitude comparison direction finding technology with eight pulse controled signal channels.

3. The dynamic range levels of the prototype in question are still satisfactory at the present time. However, if electrically regulated attenuation devices were increased, results would be better.

4. Due to microwave receiver technology already being very mature, the amount of frequency expansion operation is small.

5. The receivers in question have good inhibition results with regard to pulse signals. The degree of inhibition of pulses with duty ratios that are 1% reaches 20dB.

6. When there is the appearance of multiple signals, theoretically, azimuths should be vector sums associated with various target azimuths.

7. Due to portions of circuitry, in actuality, not being related to antennas, this system is very easy to calibrate.

4 CONCLUSIONS

Phase discrimination method continuous wave direction finding systems employ amplitude/phase transformation technologies. Through phase discrimination, measurements are realized of the angles at which continuous wave radar signals arrive. Inadequacies associated with currently existing CW direction finding technology are comparatively well overcome. Receivers are easy to calibrate. There is interchangability. It is possible to make appropriate use of direction finding systems with any number of antennas. Prototype tests demonstrate that, making use of the technology in question, it is possible to obtain relatively good direction finding precisions and sensitivities. Moreover, this possesses the characteristics of simple structures, low costs, and flexible utilization. In particular, use is appropriate in reconnaissance and direction finding associated with continuous wave radar.

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LASER COUNTERMEASURES TECHNOLOGY

Hu Jianghua Zhou Jianxun Zhang Baomin

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ABSTRACT This article starts out from the technological path associated with laser technologies. It stresses descriptions of research developments associated with such laser countermeasures as laser alarms, active laser jamming, laser protection, and so on. In conjunction with this, it puts forward several points of view with regard to the development of laser countermeasure technologies.

KEY TERMS Laser countermeasures Laser alarm Active laser jamming Laser protection Laser smokescreen Countermeasures

1 INTRODUCTION

Monochromatic characteristics of lasers are good. Directionality is strong. Coherence characteristics and brightness are high. Applications in military realms are more wide ranging and deep with every passing day. Applications of lasers in the military include laser rangefinders, laser target indicators, laser radars, laser guidance, laser weapons, and so on. Laser weapons can also be divided into high energy laser weapons and low energy laser weapons (laser blinding weapons). Applications of lasers on the battlefield constitute an extremely great threat with regard to various types of military targets. This then stimulates the development of laser countermeasures.

This article starts out from the path of laser countermeasure technology and describes the progress of research associated with laser countermeasure technologies such as laser alarms, active laser jamming, battlefield laser protection, and so on.

2 LASER COUNTERMEASURES TECHNOLOGY

2.1 Laser Alarms

Timely detection, and, in conjunction with that, discovering the laser threat, is the foundation of implementing defenses and countermeasures. When the other side is in the midst of using laser devices--making use of laser detection and alarm systems--it is not only possible to carry out laser alarms (sending out sound or visual warnings). It is, moreover, possible to detect certain laser parameters--for example, the locations of laser light sources, the direction from which laser attacks are coming, laser wave lengths, energies, repetition frequencies, as well as encoding, and so on.

After obtaining the opponent's laser pulse characteristics or wave lengths, it is necessary to rapidly determine what type of laser beam has been detected. The reaction speeds of laser alarm receivers must be adequately fast. Only then is it possible to adopt corresponding countermeasures within the extremely short periods of time described above. Due to the fact that it is not known when enemy laser beams will come and from what direction, as a result, warning receiver fields of view must be quite large. It is best to be able to do fixed view monitoring of the entire hemispherical air space. If this is not possible, scanning must then be carried out with regard to air space security. In order to be able to accurately implement fire power countermeasures, it is also necessary that warning receivers be able to do precise positioning with regard to laser devices.

Outside China, since the early 1970's, research and development had already begun on laser warning reception technology. A certain number of types of laser warning receivers have already been developed. Seen in terms of operating principles, there were two types--spectral recognition and coherence recognition. Seen in terms of operating methods, there were two kinds--direct intercept and scattering detection. Looked at in terms of operating wave lengths, most were within spectral response ranges associated with $0.45-1.1\mu m$ silicon detection devices.

The basis for spectral recognition is the wave lengths of

military lasers. They are limited in number. If detection is made of energies associated with a certain wave length among these, then, it is very possible that they were produced by lasers. On the basis of differences between models of detectors used, this type of warning receiver can also be divided into nonimagery models and imagery models. /2

No matter whether it is nonimagery or imagery spectral recognition methods, in all cases, there is no capability to detect laser wave length. Laser recognition capabilities are comparatively low. False alarms are relatively high. Coherence recognition methods, by contrast, overcome these difficulties. Moreover, it is, at the present time, the only method which is capable of measuring laser wave length. Coherence recognition models are based on the high degree of time period coherence of lasers in order to detect and recognize laser radiation. They opt for the use of interferometers to act as sensors. Laser light is incident and then produces interference patterns. Background light is incident, but, by contrast, does not produce interference patterns. As a result, laser recognition capabilities are strong. False alarms are low. Moreover, there is a capability to measure wave lengths. As far as interferometers used are concerned, there are two types--Fabuli-Poluo (phonetic) and Michelson models. The former is already a completed engineering prototype, as the MWR multiple sensor laser warning subsystem developed by the U.S. Perkin-Elmer company. Because of the fact that, during operations, interfereometers require rotation scanning, there is, therefore, no capability to detect single instances of short laser pulses. The latter--for example, the LARA laser warning test system developed by the U.S. Systems Research laboratories--opts for the use of improved Michelson interferometers and planar array CCD imaging instruments. There is no need for scanning. It is possible to detect single instances of short laser pulses. However, detection sensitivities are low.

At the present time, such countries as the U.K. have already developed more than ten types of products. In conjunction with this, units have already been equiped and are using them. Laser warning receivers--for example, the 453 model laser warning receiver produced by the U.K. Feilandi (phonetic) company, the U.S. AN/AVR-2 laser warning receiver, as well as Germany's Ablerich laser warning system--are capable of development in two directions. One is the expansion of operating wave bands to far infrared wave bands. Second is to take laser warnings and infrared and radar warnings and combine them into a multiple sensor integrated photoelectric radar warning system.

2.2 Active Laser Jamming Technology

As far as laser systems emiting laser light against an opponent to carry out jamming are concerned, it causes the other side not to be able to operate normally. It is a type of active countermeasure. Active laser jamming can be divided into two methods--laser deception type jamming and laser blinding type suppression jamming.

2.2.1 Laser Deception Type Jamming Technology

With regard to laser rangefinding deception type jamming systems, they emit high repetition frequency laser pulses, making the other side's laser rangefinders--no matter when they are turned on to do rangefinding--receive jamming pulses in all cases, creating rangefinding errors and confusion. The main characteristic is that there is no need for precise aiming. Using comparatively small power energies, it is then possible to create effective jamming against rangefinders.

With respect to the jamming of laser guided bombs or missiles, it is possible to opt for the use of decoy laser beams.

Their wave length, repetition frequency, and encoding are all the same as the other side's target indication laser, thereby luring laser guided bombs or missiles to fly toward false targets, protecting the real targets.

Since the 1970's, the U.S. has developed laser warning and jamming devices. Various nations all--to different degrees--carry out research in this area. The primary problems existing at the present time are low jammer reliability and cost benefit ratios that are not high. Following along with spectral widening out associated with solid lasers--as far as tunable and nonlinear light sources are concerned--with the appearance of flexible laser applications, high power laser technologies used in laser countermeasures have made obvious progress.

2.2.2 Laser Blinding Type Suppression Jamming Technology

Tactical weapons making use of high brightness laser beams to interfer with or destroy human vision or photoelectric sensors in various types of weapons systems are generally designated as laser blinding weapons.

As far as large numbers of battlefield sensors, which are the most commonly seen, are concerned, due to the high directionality of lasers as well as focusing functions of eyes on laser light, retinas are made very easily subject to laser damage and blindness. With regard to personnel observing the battlefield through optical telescopes, this type of damage is even more severe.

Laser blinding weapons are one type of effective photoelectric countermeasure weapon in modern warfare and also a kind of suppression weapon.

At the present time, a good number of nations all put emphasis on the development of laser blinding weapons. In conjunction with this, secrecy about it is extreme. The reason laser blinding weapons are getting serious attention is because they have, at a minimum, the characteristics that follow. One is that their power requirements are comparatively small. In technical terms, they are relatively easy to realize. Two is that, through blinding photoelectric equipment and personnel, it is basically possible to complete projected tactical objectives. Three is that manufacturing costs are low, facilitating popularizaton. Four is that, when fired, there is no recoil. There is no need for enormously expensive ammunition, rear services safeguard systems, or soft kills and damage, etc.

In the area of research on laser blinding weapons, the U.S. already has a history of more than 20 years. In the 1970's, the "Huji (Mongolian Oak Chicken)" close range combat laser weapon project was put forward. In the late 1980's, such multiple laser weapons projects as the "Stingray" dazzle device and the "Jaguar" were put forward. /3

Speaking in terms of laser blinding weapons and laser emission devices, early on, many opted for the use of Nd:YAG lasers. Following that, option was made for the use of plank shaped Nd:YAG lasers and variable frequency sapphire and emerald lasers. Seen from the point of view of development, option will be made for the use of solid lasers with diode pumps. Moreover, among these, this type of "skip wave" laser, possessing variable frequency characteristics, will be subject to even more serious attention. This is due to the fact that the threat capabilities associated with this type of laser are greater and more powerful.

2.3 Battlefield Laser Protection

As far as possible methods for protecting the eyes of battlefield personnel and the sensors of photoelectric equipment from being subjected to harm from the other side's laser weapons

are concerned, they include blocking laser beams and altering battlefield personnel methods of observation.

Methods for blocking laser beams, which can be used, include making use of dyes in optical materials (for example glass or plastic), making use of optical coatings in order to attenuate light (reflection or diffraction), and making use of high speed switching in order to cut off light.

The first type of method is capable of going through absorption model light filters for realization. The second type is capable of being realized by going through interference or diffraction models of optical filter. With regard to requirements associated with filters, they are that they not only be capable of blocking the specially designated wave lengths of laser light used but also must, as much as possible, be capable of transmiting other wavelengths of light in order to guarantee the carrying out of combat missions such as target detection, monitoring, and so on.

Up to now, optical filters which have been most widely used in the military are absorption models of optical filters. They can be almost any color. They can use glass or plastic in their manufacture. They are capable of absorbing one or multiple types of specially designated wave lengths of most optical energies. Glass absorption optical filters can withstand comparatively strong laser light. They are not easily hurt by wiping. However, antishock characteristics are relatively bad. Antishock characteristics of plastic optical filters are good. They are light weight and easily worked. However, they are easily damaged by wiping. Under strong laser irradiation, they are capable of saturating or bleaching out, losing their protective effect. Absorption models of laser protective materiel ususally have absorption band widths that are comparatively wide. The result is to create drops in transmission rates for visible light. On site, they get dark, and, in conjunction with that, become colored.

Reflective models of optical filters are vapor plated multiple layer media films on a glass substrate. They make use of optical interference principles. They selectively reflect specially designated wave lengths of laser light. Moreover, they are also capable of transmiting other wave lengths of light in visible light zones in the vicinity of the wave lengths in question very well. Compared to optical absorption filters, reflection model optical filters reflect light and do not absorb light. As a result, they are capable of withstanding greater laser powers. Therefore, interference models of reflecting optical filters mostly act as coatings added to the tops of absorption filters.

Diffraction models of optical filters are a type of new

model material to block laser light, developed on the foundation of research work associated with holographic optical components. They use holographic photography methods to make three dimensional phase gratings on glass or plastic substrates. On the basis of Prague diffraction principles, when laser irradiation reaches this type of lens, if laser irradiation angles satisfy Prague conditions (that is, sin■=■/2■x--in equations, ■ is irradiation angle, ■ is laser wave length, ■x is hologram interference pattern interval--), then, very strong first order diffraction light will be produced. At this time, it looks similar to the production of lens surface reflection on the lens. In terms of theory, the reflection factor is capable of reaching 100% of any value. The wave length which is capable of producing the strongest reflection is called the hologram wave length. It is twice the interval associated with hologram interference patterns. As a result, through control of the intervals associated with hologram interference patterns, it is possible, in accordance with protective requirements, to reflect specially designated wave lengths of laser light and cause other wave lengths of light to pass through. The characteristics are as follows. (1) Reflection band widths are narrow--generally, nanometers. As a result, not only is it possible to effectively reflect specially designated wave lengths of laser light. There are also good visible light penetration rates. (2) It is possible to use the same kind of materials to manufacture protective materiel to deal with different wave lengths of laser light. For example, the U.S. military's "holographic laser protective face guard". This is one type of diffraction model laser protective materiel. It was developed by the Hughes Aircraft company in support of the U.S. Navy in 1981. The face guard in question fits on pilots' helmets. For the sake of convenient manufacture, face guards are composed of four subassemblies. Each subassembly is formed by the superposition of two holographic reflection plates. As far as the holographic protective face guard is concerned, at the present time, it is still in the development stage. Its primary characteristics are as follows. (1) Optical density (at 0.5μm positions) OD=1.52-4 (changes along with angles of incidence). (2) Reflection band width is 22nm. (3) Visible light penetration rates are 63%-84%.

(4) Hologram recording materiel is dichromate dope.

Making use of fast switching technologies is an important development direction associated with laser protective systems. As far as the utilization of fast switching is concerned, it is then possible to cope with any wave length of high power laser light. One form of possible design associated with this type of technology is to make use of nonlinear optical polymer materials in order to manufacture optical switches or optical limiting devices. When these materials exist in strong light or strong electrical fields, their optical characteristics will change, giving rise to fast molecular polarization changes. When they

are subject to laser irradiation, they are almost opaque to laser light. Moreover, when laser pulses are concluded, they again return to a transparent condition. Components manufactured with these materials are able to block laser pulses. At the same time, they permit ordinary light that is not too bright to pass through and then exibit virtually no changes. /4

2.5 Laying Laser Smoke Screens

The laying of laser smoke screens is not only capable of making the enemy have difficulty acquiring targets, it is also able to scatter and absorb laser energy, thus lowering the danger of the threat to battlefield sensors and personnel. Smoke screen results depend on the class of smoke, the dimensions of smoke particles, laser wave length, as well as smoke layer thickness. When smoke particle dimensions approach laser wave lengths, laser energy that is scattered is more than laser energy that is absorbed. The dependence of scattering on laser wave length is even greater. In conjunction with this, blue light wave lengths are the clearest. The laying of smoke screens normally uses smoke generators. What is worth pointing out is that smoke is a type of auxiliary countermeasure. Its use will influence the performance of many types of photoelectric systems, thus influencing combat results. At the same time, it requires large amounts of rear service support and is also influenced comparatively greatly by such weather conditions as wind, humidity, and so on. Moreover, there is also a certain difficulty associated with the need to do timely laying of smoke screens to achieve predetermined results.

At the present time, despite the fact that, domestically and abroad, quite a few types of smoke weapons are produced, as far as their countermeasure effectiveness is concerned, however--in particular, comprehensive countermeasure results such as (illegible) considered (illegible) certain types of laser smoke screens are capable of countering which laser frequency spectra? At the same time, are they capable or not of effectively dealing with visible light and infrared reconnaissance (illegible)? As a result, how to check comprehensive countermeasure results associated with smoke screens, and, in conjunction with that, the putting forward of overall perfomance indices for smoke screens are problems worthy of earnest study. Work must be done in the two areas of theory and experimentation.

2.5 Laser Stealth Coating Materials

Laser stealth coatings are an important means associated with the countering of lasers. They have at least three great advantages. Applications are wide. Use is convenient. (Illegible) moving or stationary targets. There are possibilities for the creation of various types of mixed colors, thus achieving the objective of camoflage. Also (illegible) on such surfaces as (illegible) making special laser stealth coverings, laser stealth shrouds, and so on, and so forth, are self-defense (illegible) with good prospects.

The most important requirement associated with laser stealth coatings is low reflection factors. Besides this, there is also a requirement to have good physical and chemical properties--for example, resistance to (illegible), resistance to erosion by wind and rain, resistance to violent vibration, resistance to bending, as well as the possession of strong adhesive power, and so on, and so forth.

At the present time, laser stealth coatings have already been developed domestically which are capable of making near infrared laser echo powers attenuate 23.25dB. Various nations are all in the process of active development of laser steatlh coatings. In conjunction with this, security with regard to it is great.

What is worth paying attention to is that, on the basis of equilibrium state radiation theory, the low reflection factors which laser stealth coatings require necessarily cause high infrared emission rates--disadvantageous to infrared stealth. As a result, there is a need to carry out research associated with combined infrared and laser stealth coatings. Due to the fact of being subject to limitations associated with equilibrium state radiation theory, in the composite stealth research that has been launched, research work remains on the combination of low infrared emission rates and laser (illegible) reflection properties. If it is possible to use targets during stealth processes to act as objects associated with nonbalanced systems for purposes of processing, they are not subject to the restraints of currently existing radiation theory. Setting out from the realization of combined stealth objectives, it is possible to give complete evaluation forms and methods with regard to composite stealth coating properties.

2.6 Other Countermeasures

Besides the countermeasures above, other methods of countering tactical lasers also include laser shielding and the use of false targets. Any type of intelligence related to enemy laser weapons is collected. When necessary, evasion activities are adopted. Use is made of the terrain and vegetation to shield targets. Rigorous training is carried out of battlefield

personnel, mastering knowledge related to laser weapon protection, improving psychological qualities, and so on.

3 SEVERAL POINTS OF VIEW

(1) Due to full speed development in photoelectric guided weapons--in particular, the development of laser guided weapons--as well as latent threats associated with tactical laser weapons, various nations of the world--particularly the U.S.--have paid very serious attention to research on laser countermeasure technologies and the countering equipment. /13

(2) At the present time, laser countermeasure technology research is in a preliminary phase. We should give it adequately serious attention, constantly paying attention to research trends in advanced countries--overtaking advanced world levels.

(3) At the same time as carrying out laser countermeasure technology research, stress should be laid on research associated with multiple wave band comprehensive countermeasure technologies--for example, laser and infrared countermeasure technologies, laser and radar early warning, etc.

(4) As far as new materials associated with countering lasers are concerned, they are the foundation of laser countermeasure technology. As a result, research on new materials should be strengthened.

(5) Due to the fact that it will not be long until laser blinding weapons are introduced on the battlefield, as a result, research on problems associated with countering laser blinding seems very urgent.

(6) Photoelectric countermeasures should use laser countermeasures as a focal point, striving to improve the level of infrared countermeasures, and strengthening research on visible light countermeasures.

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